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RARE PLANTS OF NĀULU FOREST AND POLIOKEAWE PALI, HAWAII VOLCANOES NATIONAL PARK

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ABSTRACT

During a 1993-95 survey of Nāulu Forest remnants and other kipuka on Hōlei and Poliokeawe Pali in Hawaii Volcanoes National Park, one proposed endangered and one candidate endangered plant species were found and mapped. Sixteen hala pepe (Pleomele hawaiiensis) were observed; seven were small plants, indicating natural regeneration. Forty-six mature 'ahakea (Bobea timonioides) trees were counted; no seedlings were observed. Seven other rare native tree and shrub species were found in the study area. Only two hame (Antidesma pulvinatum) and one kolomona (Senna gaudichaudii) were found on the eastern side of one kipuka (Area I). This is the only Park site known to support hame and one of few sites with kolomona shrubs. Only three 'ohe (Reynoldsia sandwicensis) were seen in the study area: two on Poliokeawe Pali and one in the western Nāulu kipuka (Area II). This tree has become very rare in the Park because of forest destruction from recent lava flows. Three maua (Xylosma hawaiiense) were observed, one in each of three study area kipuka (Areas I, II, and IV). Hao (Rauvolfia sandwicensis) occurred primarily in the easternmost large kipuka of the study area (Area I), where 26 trees were sighted. One additional hao tree was found in a small grove farther east (Area III). 'Iliahi (Santalum paniculatum) and naio (Myoporum sandwicense) are uncommon species in the Park; both had sizable populations in Nāulu Forest, particularly in the Kealakomo kipuka (Area II) on Hōlei Pali.

Density and size class structure of four common native tree species were determined in the two largest Nāulu Forest kipuka (Areas I and II). Lama (Diospyros sandwicensis) was the most common tree with densities of 89.3 and 171.3 plants/ha in Areas I and II, respectively. The lama population was composed primarily of mature trees. Alahe'e (Canthium odoratum) and naio (considered a common species in one kipuka) displayed stable population structures with many young plants. A few young māmane (Sophora chrysophylla) occurred at low density in only one kipuka (Area I). Thirty-six alien plant species were observed in the two intensively surveyed kipuka; those with highest cover and frequency along transects were lantana (Lantana camara), three other shrub species, scaly swordfern (Nephrolepis multiflora), and four grass species. Alien grasses pose a threat to rare plants because of their ability to carry fire; lantana and other shrubs may interfere with rare plant reproduction.

ACKNOWLEDGMENTS

This survey was part of a larger Special Ecological Areas research project that was planned and coordinated by Dr. Charles Stone. We wish to thank David Palumbo and Nick Shema for their assistance in establishing transects and gathering native plant data. Comparisons of extant rare plant populations with former numbers and localities would not have been possible without the rare plant species information and maps compiled by N. G. (Chris) Zimmer of the Resources Management Division, Hawaii Volcanoes National Park (HAVO). We appreciate the unrestricted access to his unpublished files and maps so generously granted. We also wish to thank Tim Tunison, Chief of the HAVO Resources Management Division, and Dr. Clifford Smith, Director of the University of Hawaii Cooperative National Park Resources Studies Unit, for reviewing an earlier version of this report. Finally, we would like to acknowledge Diane Butler, who greatly assisted in the production of the final report.

INTRODUCTION

Nāulu Forest is one of 23 designated or proposed Special Ecological Areas (SEAs) in Hawaii Volcanoes National Park. These SEAs are the most intact and species-rich ecosystems in the Park and are the focus of management, particularly alien plant and animal control (Tunison et al. 1986). Currently 12 Park SEAs with a total area of 12,146 ha (30,000 a) are actively managed by removing feral animals and invasive weeds, and an additional 11 areas (including Nāulu) have been proposed for more intensive management when funds become available (National Park Service 1996).

Despite its small size, Nāulu Forest is one of the most diverse native dry forests within the Park. Although rain forests garner more attention, dry forests are the most threatened of tropical forest types (Janzen 1988). Dry and mesic forests are often refugia for rare plants and have been recognized as centers of plant diversity in Hawai'i (Rock 1974, Stemmermann and Ihsle 1993).

Nāulu Forest has long been considered an important site for rare and endangered plant species. The first known botanical survey of the area was done by G. O. Fagerlund and A. L. Mitchell in the 1940s; they collected many specimens in Nāulu and included their distributional information in an early plant checklist of the Park (Fagerlund and Mitchell 1944). Benjamin Stone briefly surveyed the Nāulu area while compiling a checklist of plants of the Kalapana Extension (Stone 1959). The vegetation of Nāulu was described in detail as part of an extensive transect in a Park-wide ecological study in the early 1960s (Doty and Mueller-Dombois 1966). F. R. Warshauer surveyed the Kealakomo region (including Nāulu) following the Mauna Ulu lava flows of 1969-74; he described vegetation, counted rare plants, and evaluated potential threats (Warshauer 1974). The most recent surveys of Nāulu Forest and the adjacent Poliokeawe Pali were

carried out by N. G. Zimmer of the Park's Resources Management Division for the purpose of mapping rare trees and collecting seeds for future outplanting and restoration (Zimmer 1982-83).

The primary objectives of the survey reported here were to locate rare plants in Nāulu Forest and nearby kipuka on Poliokeawe Pali, map their current distribution and abundance, determine their population structure, and evaluate threats to their continued existence. Data were also collected on common native tree species of the forest to evaluate the stability of the rare plants' habitat. The vascular plants found in the two primary Nāulu kipuka were listed to document the current species composition of the dry forest (Appendix I). This study was part of a larger research project designed to carry out systematic vegetation monitoring in selected SEAs, to document recovery from past disturbance, and to provide information on rare plants and natural communities (Stone and Cuddihy 1990).

STUDY AREA

Nāulu Forest is located on the south-facing slope of Hōlei Pali and the easternmost extension of Poliokeawe Pali between 180 m (600 ft) and 600 m (2,000 ft) elevation in Puna District within Hawaii Volcanoes National Park (Fig. 1). This region of the Park is transitional between the coastal lowlands and the mid-elevation forests and shrublands. Portions of the Nāulu Forest, as well as forests and shrublands of Poliokeawe Pali, were covered in 1970 and 1972 by lava flows from the eruption at Mauna Ulu (1969-74). Today, only remnant vegetated kipuka remain, where formerly there was a semi-continuous forest above the pali with lobes of dry forest vegetation reaching downslope along the cliff face. Three primary study areas were defined by remaining kipuka on Hōlei Pali (Areas I, II and III). Additionally, the forested part of a kipuka between Hōlei and Poliokeawe Pali in Kahue ahupua'a (Area IV) was briefly examined, and portions of Poliokeawe Pali in 'Āpua ahupua'a west to the 'Āinahou boundary (6.5 km west of Area I) were surveyed for rare plants (Fig. 2).

Area I is the kipuka south of the benchmark at 594 m (1,697 ft) elevation on the Chain of Craters Road; the surveyed portion of this kipuka between the upper and lower stretches of the road is approximately 41 ha in size (Fig. 2). It is the most densely vegetated kipuka remaining on Hōlei Pali and has a prominent grove of kukui (Aleurites moluccana) visible from the road. Area II is the kipuka below Kealakomo shelter to the west of Area I; the surveyed part of this kipuka is approximately 34 ha. Both Areas I and II are in the Kealakomo ahupua'a. Area III is in Pānau Nui ahupua'a directly east of Area I across a 1972 pāhoehoe flow, and is composed of a series of five small kukui groves, with about 2 ha in total area. These small kipuka of Area III are all within the hairpin curve of the Chain of Craters Road.

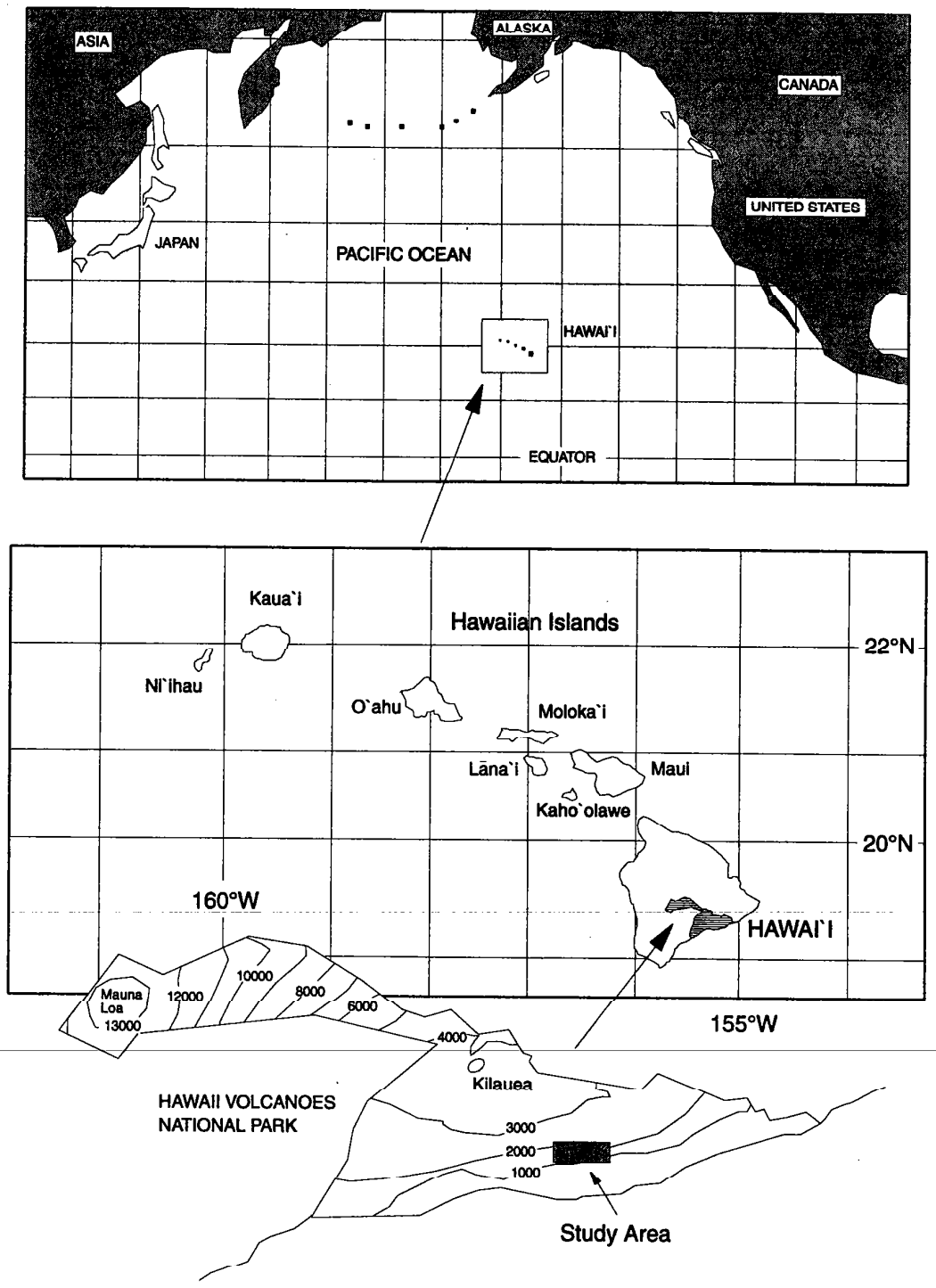


Figure 1. The study area in the eastern lowlands of Hawaii Volcanoes National Park, island of Hawai`i (Hawaiian Islands in upper illustrations).

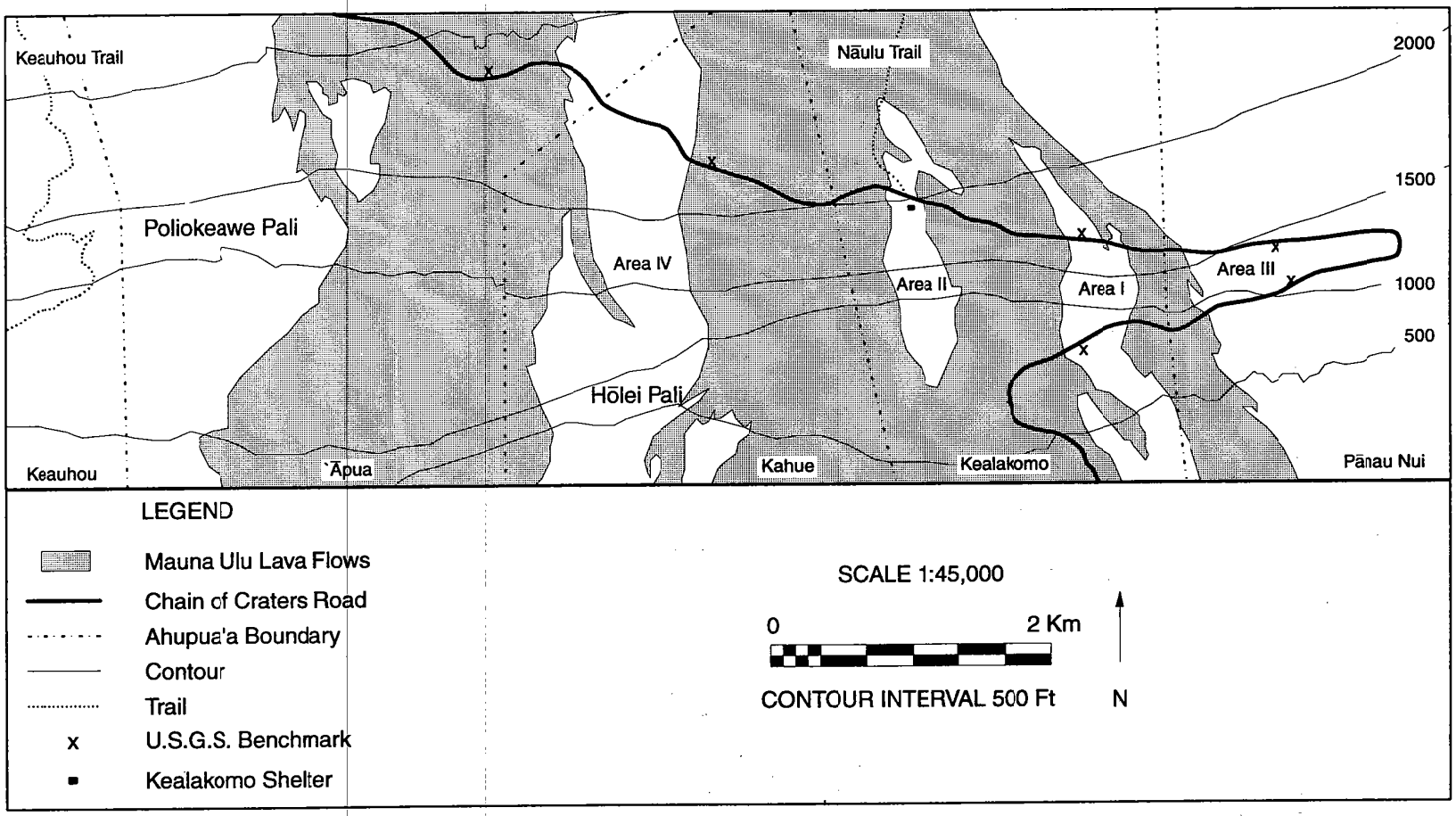


Figure 2. Location of Areas I, II, III, and IV on Hōlei and Poliokeawe Pali in Hawaii Volcanoes National Park.

Geology and Soils

Hōlei and Poliokeawe Pali are part of the Hilina Pali fault system, which includes many prominent cliffs and scarps of the southern flank of Kilauea Volcano (MacDonald et al. 1983). Slopes on the pali are very steep (80%), and the substrates of the several surveyed kipuka consist of prehistoric lava flows and talus of 'a'ā boulders. The lava flows under the forested parts of the two primary Nāulu kipuka (Areas I and II) and the very small kipuka of Area III are 500 to 750 years old (Holcomb 1987). These flows originated at Kāne Nui o Hamo, a lava shield at 1,085 m (3,100 ft) elevation upslope on Kilauea's East Rift. Both pāhoehoe and 'a'ā are found within the two kipuka of Area I and II. The substrates of the Area IV kipuka and Poliokeawe Pali are younger Keauhou flows, 300-500 years old (Holcomb 1987). None of the surveyed areas have appreciable soil development, but are classified as pāhoehoe and 'a'ā lava flows with little soil cover (Sato et al. 1973).

Climate

The climate of Nāulu Forest and the surrounding area is warm and dry with drought periods occurring in the summer (Doty and Mueller-Dombois 1966). Mean annual rainfall in the Nāulu Forest area is 1,500-2,000 mm (59-79 in), and rainfall is less than 1,500 mm/year to the west on Poliokeawe Pali. At the nearby Kalapana station (southeast of Nāulu), mean annual precipitation is 1,441 mm (57 in); driest months here are June and July, which have less than 25% of the mean January rainfall (Giambelluca et al. 1986). Mean annual temperature in this general region is 21.1-24.4°C (70-76°F) (Hawaii Department of Land and Natural Resources 1970).

Vegetation

The forest vegetation of the two primary Nāulu kipuka may be classified as 'ōhi'a lehua/lama lowland mesic forest or lama lowland dry forest (The Nature Conservancy 1990); both forest types are considered rare or locally distributed in a restricted range (The Nature Conservancy 1987). These forests are dominated by 'ōhi'a lehua (Metrosideros polymorpha) and lama (Diospyros sandwicensis) and contain other native tree and shrub species in the understory. On steep talus slopes, in Areas I and III, kukui is the dominant tree species in groves within 'ōhi'a lehua/lama or lama forest. Mueller-Dombois speculated that these kukui groves were due to sub-surface irrigation from seepage water (Doty and Mueller-Dombois 1966). 'Ōhi'a lehua lowland dry forest surrounds the dense core of lama or mixed forest vegetation of the two primary kipuka.

Jacobi (1982) mapped the central portions of both Area I and II kipuka as closed tall 'ōhi'a lehua dry forest with other native trees and shrubs. He mapped the northern and southern extremes of the two kipuka as scattered to open 'ōhi'a lehua dry forest with native shrubs, alien shrubs, and exposed bare substrate. The vegetation of the five small Area III kipuka was mapped as closed tall kukui/'ōhi'a lehua dry forest with native

understory trees. Jacobi classified the Area IV kipuka as a mosaic of vegetation types, including open 'ohi'a lehua dry forest with native shrubs and alien shrubs and grasses; scattered 'ōhi'a lehua with shrubs and bare ground; and very scattered 'ōhi'a lehua with alien grasses and mixed shrubs. The surveyed portion of Poliokeawe Pali was mapped with vegetation types similar to those of the Area IV kipuka. The recent lava flows separating the kipuka were mapped as bare by Jacobi in 1982 and remain nearly devoid of vegetation today.

Former Land Uses and Grazing

The eastern lowlands of what is now Hawaii Volcanoes National Park were formerly inhabited by Hawaiians, who built villages on the coast and also cultivated and gathered materials from the uplands. Waha'ula, a site east of the study area, was inhabited before 1300 AD. Archaeological surveys of the Kamoamoa/Waha'ula sites have identified more than 15,000 features, including 13,000 agricultural components (Ladefoged et al. 1987). Many of these agricultural remains were mounds for growing 'uala or sweet potatoes (Ipomoea batatas). Kealakomo, directly downslope from Nāulu Forest and Areas I-III, was a populous coastal village when visited by William Ellis in 1823 (Ellis 1963). Reverend Ellis was able to gather at short notice (about a day) 200-300 people to hear his sermons at Kealakomo. The site of Kealakomo was covered by lava in 1971, destroying more than 200 features in an area that had not been intensively studied (Ladefoged et al. 1987). The abandoned village site of Nāulu at the base of Hōlei Pali, just below the study area, was also destroyed by Mauna Ulu lava flows.

The size of the prehistoric human population of the Kealakomo area is not known, but at least 17 families were living there in 1859 (Allen 1979). The population of Kealakomo apparently declined in the following decades due to emigration to towns and catastrophic events, such as the 1868 earthquake and subsequent coastal subsidence. The number and size of nearby villages and agricultural sites indicate that clearing and cultivation were carried out by Hawaiians near the study area. Throughout their residence in the Kealakomo/Nāulu area, Hawaiians almost certainly used nearby forests as sources of firewood and timber for building and crafts. Burning of lowland forests and shrublands to clear for agriculture and to stimulate pili (Heteropogon contortus), an important thatching material, was also a common Hawaiian practice (Kirch 1982). Williams (1990) recorded an account of a long-time resident of Kalapana, who remembered large expanses of pili grass at Kamoamoa and Pānau Nui (east of Nāulu) around 1900.

Hawaiians had no large domestic animals other than the pig (Sus scrofa), which they apparently kept close to their villages (Tomich 1986). European domestic pigs, which were introduced to Hawai'i in the late 1700s and allowed to become feral, have been present in the study area for many years, although today the density of feral pigs in this relatively dry and rocky lowland site is quite low.

Goats (Capra hircus) were introduced to the southwestern part of Puna before 1846 (Ladefoged et al. 1987). Goat ranching was in progress at Lae 'Apuki and Pānau Iki (east of the study area) as early as 1862 (Allen 1979). By 1900, local residents were rounding up and harvesting thousands of goats each year in the Pānau and Kealakomo land divisions (Williams 1990). The various large parcels of the Kalapana Extension were acquired by the Park Service between 1938 and 1961 (National Park Service 1985); this addition included the study area, two ahupua'a west of Kealakomo, and several ahupua'a east to Pūlama (Allen 1979). Feral goats were a serious problem in the lowlands of Hawaii Volcanoes National Park, where in 1970 the goat population was estimated at 14,000, despite more than 40 years of goat control efforts (Baker and Reeser 1972). Goats were still present in the study area in 1974, particularly along the pali (Warshauer 1974). An aggressive and organized program to fence the Park lowlands and eradicate feral goats began in 1970 and resulted in the reduction of goats to remnant levels within 10 years.

Cattle (Bos taurus) ranching began in the Kamoamoa area in the 1880s (Ladefoged et al. 1987). Several local ranchers had herds of 1,000 cattle in the late 1800s, although the lowlands of Puna now within the Park were apparently considered poor cattle pasture (Williams 1990). Cattle ranching near the study site ceased in the 1940s after the Kalapana extension was authorized and the Park Service began to acquire the land for addition to Hawaii National Park.

The primary impact of both feral and domestic ungulates on the vegetation of the Park's eastern lowlands was the destruction of native woody plants. Goats are primarily browsers and are known to strip tree bark and consume tree and shrub seedlings. Where woody plants are available, goats prefer native browse over non-native grasses (Baker and Reeser 1972). Although not documented, some of the alien grasses in the study site may have been intentional or accidental introductions during the decades of cattle grazing in the eastern Park lowlands.

METHODS

Only the two most densely-vegetated kipuka of the study area were intensively surveyed from June to December, 1993. To facilitate rare plant mapping and collection of vegetation data, eight transects were established in Area I and six transects were placed in Area II; these transects ran east/west completely traversing the most densely forested portions of the two kipuka. Transects were systematically placed 50 m apart. In Area I, an existing 500-m-long north/south baseline from a former rat trapping project was used to position plant transects, and in Area II, a north/south baseline was measured along the western edge of the kipuka.

Ten-meter intervals were measured and flagged along each of the transects. The eight transects in Area I had a total of 307 10-m segments, and the six transects in Area

II had a total of 244 segments. These 10-m transect segments allowed the systematic collection of data on the density and structure of several common forest trees and the frequency and estimated abundance of non-native (alien) plants in 10-m wide belts, resulting in a sampling scheme of contiguous quadrats of 100 m^2.

For mapping rare plants, distances and compass bearings to each individual were measured from specific 10-meter interval marks along transects. These polar coordinates were converted to rectangular coordinates for mapping rare plant distributions in the Area I and II kipuka. Areas III, IV, and Poliokeawe Pali lacked transects, and rare plants were mapped using available landmarks. Data collected at each rare plant included height, diameter at breast height (dbh, 1.4 m above the base) or basal diameter, phenology, goat or rat damage, insect damage, tree condition, and presence or absence of alien plants. Phenology data recorded were the presence/absence of flowers or fruits. Presence or absence values (1 = present, 0 = absent) were summed and divided by the total number of trees observed (by species) in all areas to determine the percentage bearing flowers or fruits during the survey.

Signs of past goat browsing or bark gnawing and current rat damage were noted when present. Insect damage was recorded as 0 = none, 1 = very light, 2 = light, 3 = moderate, and 4 = heavy. Tree condition was rated as 0 = poor, 1 = fair, 2 = good, or 3 = excellent. Poor condition was characterized by trees with few or unhealthy leaves. A fair rating indicated the tree had sparse foliage, or if in full foliage, some leaves were unhealthy or dead. Good condition was typical of healthy trees with very little damage to leaves, stems, or trunks. A rating of excellent was reserved for trees that appeared to be in the best of health. These rating values were averaged for all four areas and Poliokeawe Pali. Alien plants were noted within a 5-m radius at each rare plant, and the percentage of rare plants (by species) growing with specific aliens was determined.

Individuals of four common native tree species were counted along transects in 10-m-wide belts. Lama, naio (Myoporum sandwicense), māmane (Sophora chrysophylla), and alahe'e (Canthium odoratum) were recorded in five height classes: <1m, 1-2m, >2-3m, >3-5m, and >5m. Alahe'e was counted only in Area II; alahe'e trees were too numerous in Area I to sample by this method. Density (number/ha) of the four native tree species was calculated using the total number of trees (by species and height class) in all 10-m intervals of the belt transects in Areas I (3.07 ha) and II (2.44 ha).

Cover values for alien plants were estimated in 10-m wide belts and 10-m segments along the transects using the Braun-Blanquet cover-abundance scale (Mueller-Dombois and Ellenberg 1974). The Braun-Blanquet values are + = <1%, 1 = 1-5%, 2 = >5-25%, 3 = >25-50%, 4 = >50-75%, and 5 = >75-100%. The frequency of alien plants along all transects in Areas I and II was derived by dividing the number of 10-m segments containing an alien species by the total number of transect intervals. A checklist was compiled of all vascular plants found in Areas I, II, and IV (Appendix I).

The five small kukui groves of Area III were searched for rare plants in March, 1994. Area IV, a sparsely vegetated kipuka between Hōlei and Poliokeawe Pali, was visited in January, 1995. The top and upper face of Poliokeawe Pali to the west of Area IV were surveyed in May, 1994. Systematic transects were not used in these three areas, and only rare plant data were collected during these brief surveys.

RESULTS AND DISCUSSION

During the survey of Nāulu Forest remnants on Hōlei Pali (Areas I, II, III) and several forested kipuka on or near Poliokeawe Pali (including Area IV), one proposed endangered species, one candidate endangered plant species, and seven other rare tree species were found. A summary of these nine species and their relative abundance in the four surveyed areas is presented in Table 1.

Proposed and Candidate Endangered Plant Species

Hala pepe (Pleomele hawaiiensis) - Hala pepe, a tree-like plant of the Agave Family (Agavaceae), is endemic to the leeward slopes of Hawai'i Island, where it occurs in dry forest from 300 to 860 m (980-2,820 ft) elevation (Wagner et al. 1990). Five other species of hala pepe are found in remnant dry forests on other Hawaiian Islands. The Hawai'i Island hala pepe is known from only six to eight populations, containing an estimated 250-300 individuals, and was recently proposed as an endangered species (U. S. Fish and Wildlife Service 1995). [Note: Pleomele hawaiiensis was officially listed as endangered in 1996, after this report was completed.]

During the 1993 survey, sixteen hala pepe were found, including five plants in Nāulu Forest Area I, nine in Area II (Fig. 3), and two individuals on Poliokeawe Pali (Fig. 4). Their mean height was 2.1 m, with four plants 4 m tall or taller (Fig. 5). The mean dbh for eight individuals was 6.6 cm, but the largest tree had a diameter of 19.5 cm (Fig. 6). The remaining eight plants were <1 cm dbh; the mean basal diameter of these specimens was 1.9 cm (Table 2). Seven of the nine hala pepe in Area II were 1.4 m or less in height, indicating regeneration was occurring in this kipuka. Eight of these nine plants were in close proximity to each other, making this population susceptible to any local disturbances. Other hala pepe ≤2 m tall, including three plants in Area I and one on Poliokeawe Pali, were probably planted individuals (Zimmer 1983).

Thirty-one percent of the hala pepe plants were in flower during the summer/fall survey, while only 6.3% had fruit. Only one plant had rat damage, and a few showed very light insect damage to leaves. One of the plants in Area I had its top broken by a fallen dead limb of kukui. Pieces of this hala pepe were salvaged and successfully rooted for later out-planting. Although the overall condition of the hala pepe plants was good, leaf chlorosis was observed on some individuals. This chlorosis may have been caused

Table 1. Summary of the Number of Nine Rare Native Plant Species Found in Areas I, II, III, and Poliokeawe Pali.

Species	Area I	Area II	Area III	Poliokeawe Pali*	Total
Antidesma pulvinatum Hame	2	-	-	-	2
Bobea timonioides[1] 'Ahakea	37	2	7	-	46
Myoporum sandwicense Naio	47[2]	236[3]	-	nc	283
Pleomele hawaiiensis[4] Hala pepe	5	9	-	2	16
Rauvolfia sandwicensis Hao	26	-	1	-	27
Reynoldsia sandwicensis 'Ohe	-	1	-	2	3
Santalum paniculatum 'Iliahi	1	29	-	-	30
Senna gaudichaudii Kolomona	1	-	-	-	1
Xylosma hawaiiense Maua	1	1	-	1	3

[1] Candidate endangered species (Category 2).
[2] Treated as a rare plant in Area I.
[3] Sampled as a common native tree species in Area II, and counted only along transects.
[4] Proposed endangered species.
* Including Area IV
nc = not counted

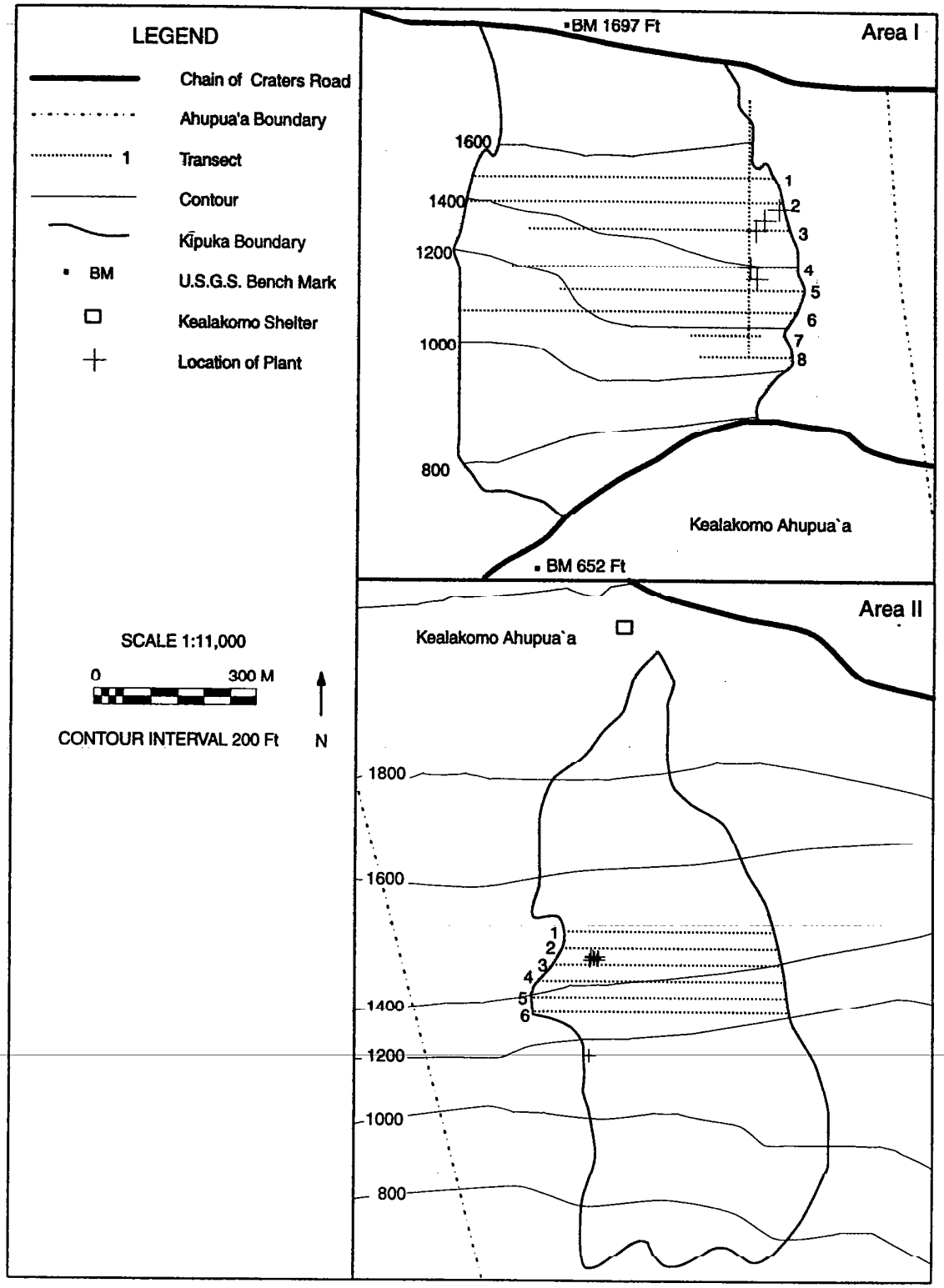


Figure 3. Distribution of hala pepe (Pleomele hawaiiensis) in Areas I and II on Hōlei Pali.

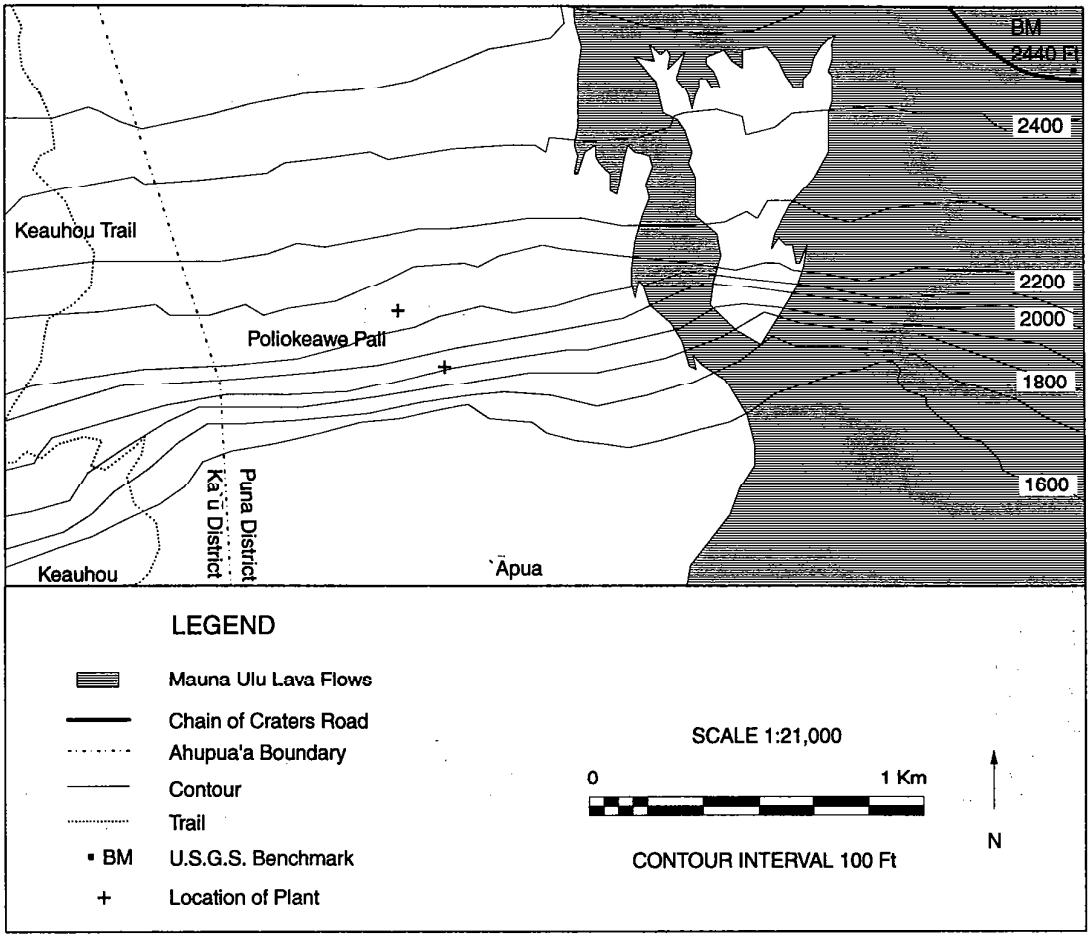
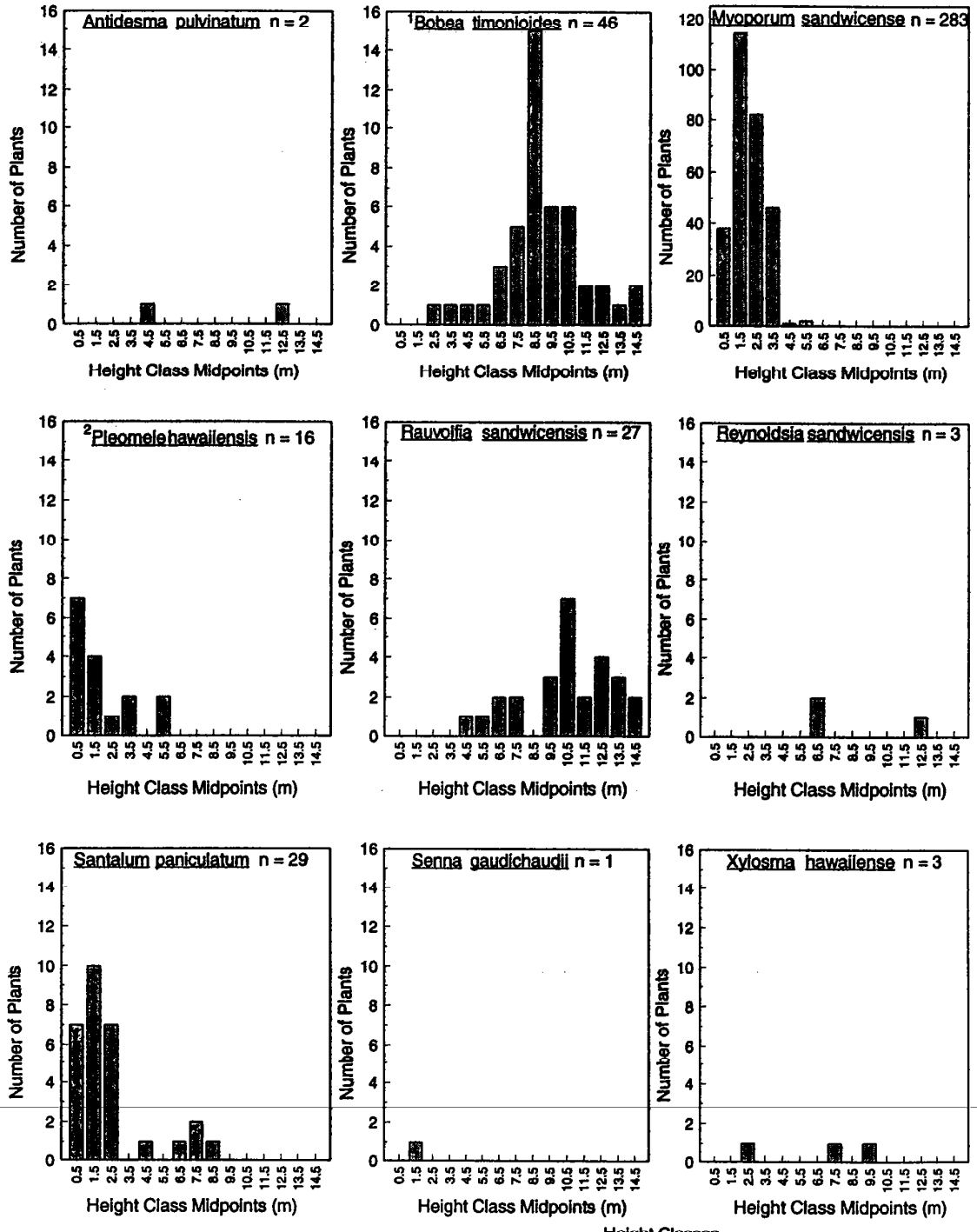
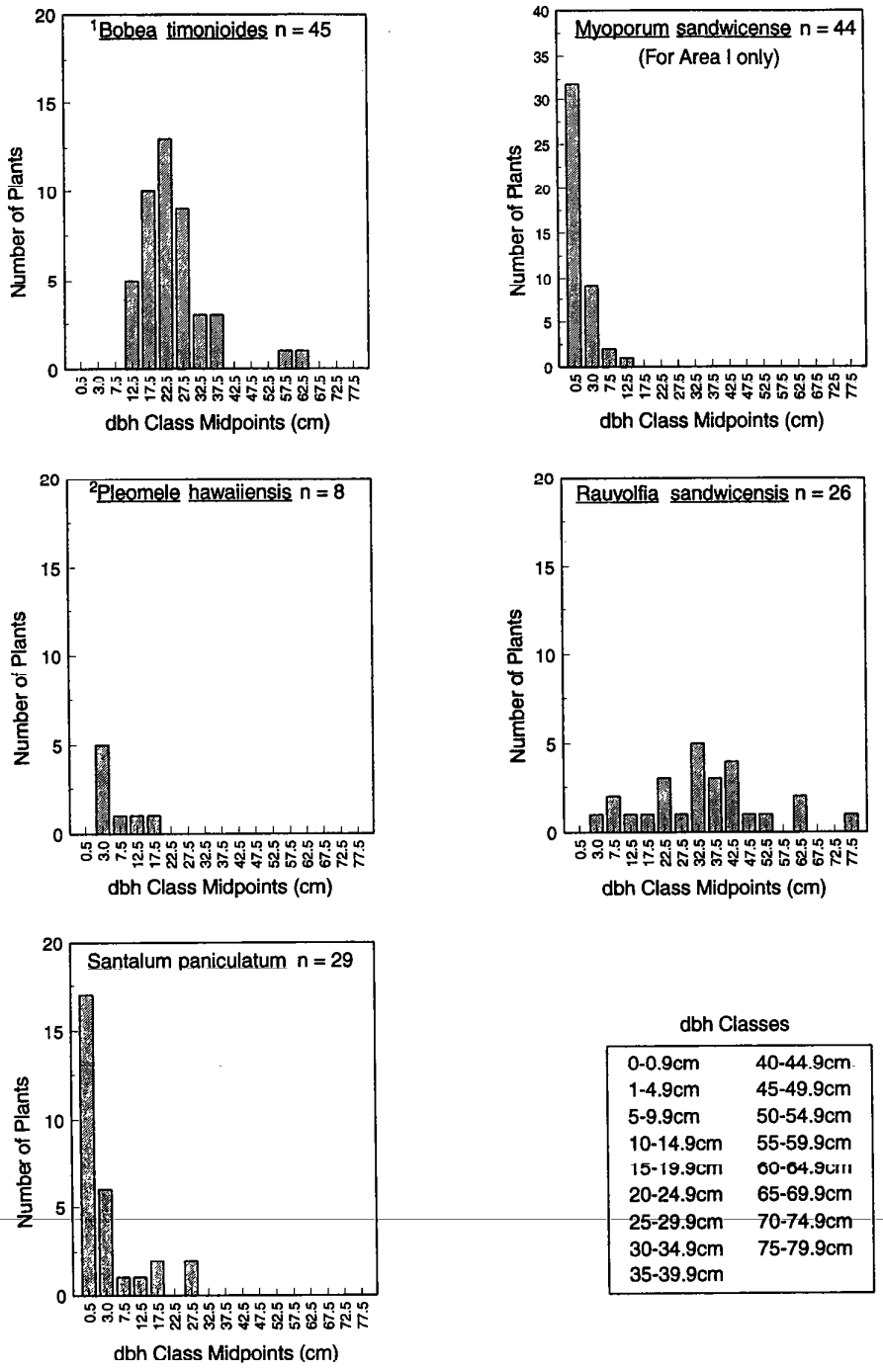


Figure 4. Distribution of hala pepe (Pleomele hawaiiensis) on Poliokeawe Pali.



[1]Candidate Endangered (Category 2)
[2]Proposed Endangered

Figure 5. Height class distribution of two endangered and seven rare native plant species from Hōlei and Poliokeawe Pali.



[1]Candidate Endangered (Category 2)
[2]Proposed Endangered

Figure 6. Diameter class distribution of two endangered and three rare native plant species from Hōlei and Poliokeawe Pali.

Table 2. Size Measurements, Phenology, Animal Damage, and Condition of Nine Rare Native Plant Species in Areas I, II, III, IV, and Poliokeawe Pali.

Species	Mean Ht. (m) (± S.E.)	Mean dbh (cm) (± S.E.)	Mean Basal Diam. (cm) (± S.E.)	Phenology % in Flower	Phenology % in Fruit	% With Goat or Rat Damage	Mean Insect Damage	Cond.
Antidesma pulvinatum Hame	9.0 ± 4.0	13.0 ± 0.9	-	0.0	0.0	50.0	V. Light/ Light	Fair
Bobea timonioides[1] 'Ahakea	8.5 ± 0.4	24.2 ± 1.5	-	39.1	52.2	56.5	V. Light	Fair
Myoporum sandwicense[2] Naio	2.1 ± 0.1	4.8 ± 1.2	8.6 ± 1.3	76.6	72.3	4.2	V. Light	Good
Pleomele hawaiiensis[3] Hala pepe	2.1 ± 0.4	6.6 ± 2.1	1.9 ± 0.3	31.3	6.3	6.3	V. Light	Good
Rauvolfia sandwicensis Hao	10.0 ± 0.5	34.3 ± 3.5	29.0	96.3	18.5	59.3	V. Light	Fair
Reynoldsia sandwicensis 'Ohe	9.0 ± 22.1	22.1	-	100.0	100.0	0.0	V. Light	Fair
Santalum paniculatum 'Iliahi	2.2 ± 0.4	10.4 ± 3.2	2.4 ± 0.6	58.6	10.3	0.0	V. Light	Good
Senna gaudichaudii Kolomona	1.2	-	1.0	0.0	0.0	0.0	Light	Fair
Xylosma hawaiiense Maua	7.0 ± 2.1	18.7 ± 9.3	-	0.0	0.0	0.0	V. Light	Fair

[1] Candidate endangered species (Category 2).
[2] n = 47 plants from Area I only.
[3] Proposed endangered species.

by sulfur dioxide fumes produced by Pu'u 'O'o, the source of the ongoing eruption. Two-spotted leaf hoppers (Sophonia rufofascia), alien insects also known to cause foliar chlorosis on host plants, were not observed in the study area but are present at nearby sites (Yang et al. in prep.).

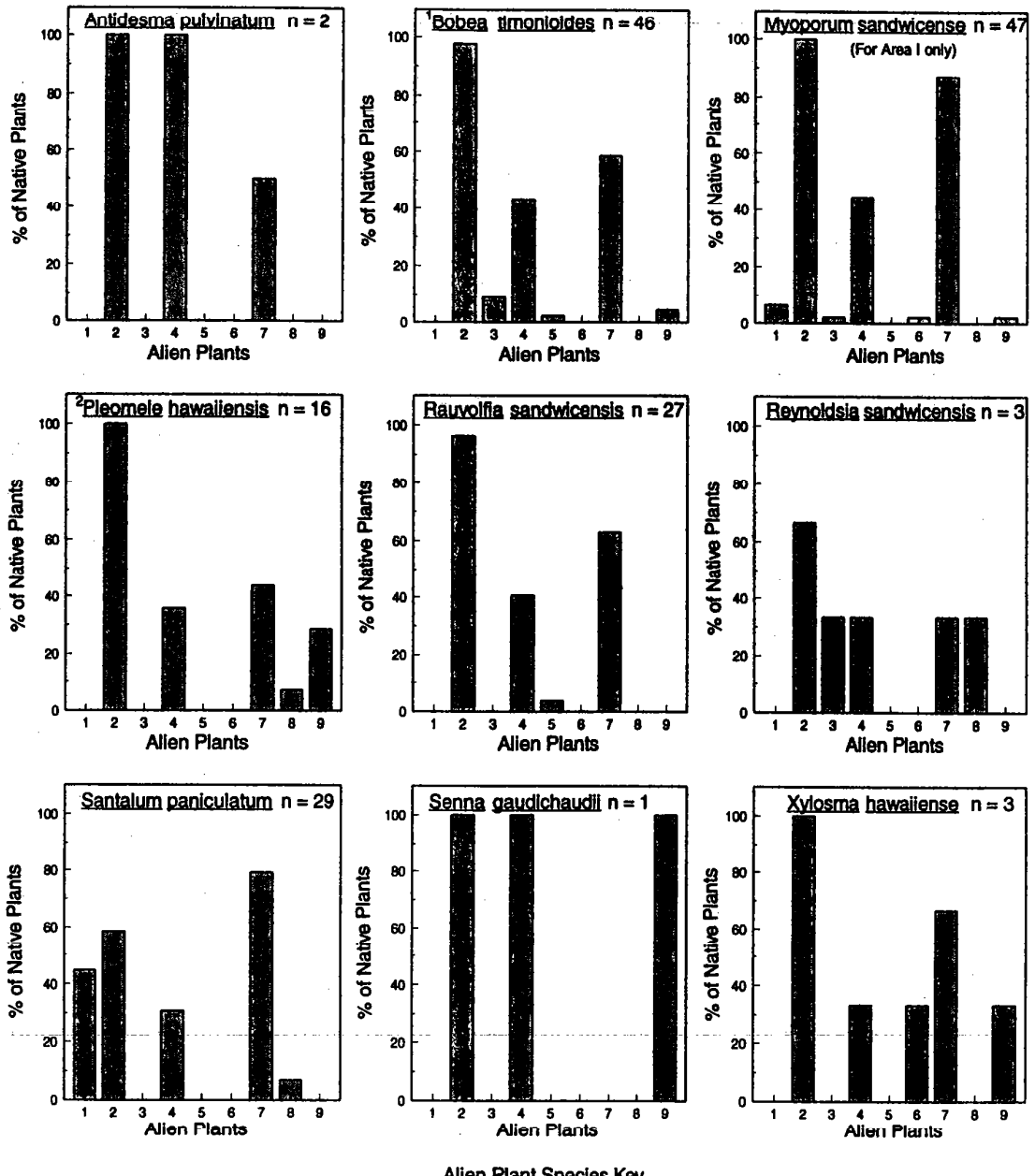
Five alien plant species were growing in proximity to the 16 hala pepe plants (Fig. 7). The most commonly seen alien plant near hala pepe was lantana (Lantana camara), but scaly swordfern (Nephrolepis multiflora) and Natal redtop grass (Rhynchelytrum repens) were present at nearly 40% of the hala pepe sites.

In his survey of Kealakomo following the creation of the Nāulu kipuka by Mauna Ulu lava flows, Warshauer (1974) found six hala pepe in Area II and one on Poliokeawe Pali; he also noted that four occurred farther down the pali east of 'Āinahou in a goat control unit. He observed no successful regeneration in the Nāulu kipuka, though he reported seedlings up to 10 cm (4 in) tall within the goat control unit. The lower part of the former goat control area (see Baker and Reeser 1972 for a map of units) was outside the current study area. Zimmer (1983) observed a total of 12 naturally occurring hala pepe plants on Hōlei Pali (two in Area I and six in Area II) and Poliokeawe Pali (four plants), but noted no natural regeneration among these plants. He also planted four hala pepe in Area I, as well as four cuttings on a small 'a'ā flow on Poliokeawe Pali in 1978 (Zimmer 1983).

Of the naturally occurring hala pepe that Warshauer observed in 1974 and Zimmer reported in 1983, two are still growing in Area I, an undetermined number remain in Area II, and only one survived on Poliokeawe Pali. Since seven of the nine plants in Area II were ≤1.4 m tall in 1993, reproduction and establishment has taken place since Zimmer's observations more than ten years ago. Perhaps three of the Area II hala pepe seen by Zimmer in 1983 remain. Of the planted individuals, one appears to have died in Area I, and three have disappeared from Poliokeawe Pali. Earlier records of hala pepe at Nāulu and Poliokeawe Pali include a 1943 collection from the pali at 488 m (1,600 ft) elevation in 'Āpua ahupua'a (Fagerlund & Mitchell 559, HAVO Herbarium), a 1975 collection from Poliokeawe Pali east of 'Āinahou (Reeser sn, HAVO Herbarium), and a report of hala pepe as "infrequent on Poliokeawe Pali" in 1959 (Stone 1959).

Hala pepe is known from only one other locality in Hawaii Volcanoes National Park. Zimmer (1983) observed a natural population of four hala pepe growing in and near the Great Crack near the Park's western boundary at 670 m (2,200 ft) elevation, and later planted four cuttings at the same site. This area was not resurveyed in 1993.

'Ahakea (Bobea timonioides) - 'Ahakea occurs in dry to mesic lowland forest in Puna and South Kona Districts of Hawai'i Island (Wagner et al. 1990). The species has also been collected on Maui, O'ahu, and Kaua'i. A tree in the Coffee Family (Rubiaceae), 'ahakea has smooth, white bark; opposite leaves with prominent reddish veins; clusters of tiny greenish flowers; and purplish-black hard fruits. A category 2 candidate endangered species, 'ahakea is thought to exist in less than ten populations statewide, with less than 500 individuals total (U. S. Fish and Wildlife Service 1994a).



[1]Candidate Endangered (Category 2)
[2]Proposed Endangered

Figure 7. Percentage of nine rare native plant species growing with nine alien plant species in Areas I-IV and Poliokeawe Pali.

During the 1993 survey, 46 'ahakea were found on Hōlei Pali, including 37 in Area I, two in Area II (Fig. 8), and seven in Area III (Fig. 9). The trees ranged in height from 3 to 14 m (Fig. 5), and their mean height was 8.5 m. Most 'ahakea were mature trees; their mean diameter (dbh) was 24.2 cm (Fig. 6). Regeneration of 'ahakea was poor in these forested kipuka. No seedlings or saplings were seen, and only two of the 'ahakea trees were less than 4 m in height.

Thirty-nine percent of the 'ahakea trees were in flower and 52% in fruit when surveyed. The Area I kipuka was surveyed in June, Area II was searched in November, and the small kipuka of Area III were examined in March. Most of the trees found in the summer bore flowers, but few of those seen in November or March were fertile. Over 50% of the 'ahakea trees had browse damage to bark at the base of trunks. The goat damage was old, probably from the 1970s. Although insect damage to leaves was very light, one tree had termite droppings in the bark of its trunk. Many 'ahakea leaf tips had been burned by volcanic fumes from the Pu'u O'o eruption. While the overall condition of the 'ahakea trees was fair, the seven individuals from Area III were in very poor condition, with dead tops, very little live foliage, many dead branches, and black fire scars on their trunks. The fire damage was probably from the Nāpau fire of 1992, which burned from Paliuli west to the Mauna Ulu lava flows. At least two earlier fires have also been documented in the area of the hairpin curve of the Chain of Craters Road (Tunison et al. in prep.).

Six alien plant species were found near the 46 'ahakea trees (Fig. 7), but only three of these were abundant. These were the same three species that occurred near most of the hala pepe plants. Lantana was nearly ubiquitous, while scaly swordfern and Natal redtop grass occurred at 40-50% of 'ahakea sites.

There were many more 'ahakea trees in the Area I kipuka than in Area II or III, indicating that this site is more favorable to the species or has been less severely disturbed. In 1970, a lava-generated fire burned some of the Nāulu Area II kipuka along with vegetation on a different substrate to the east. The boundaries of this 1970 Kealakomo fire are not precisely known, and subsequent lava flows have covered much of the burned area (Tunison et al. in prep.). 'Ahakea were concentrated on the eastern side of the Area I kipuka, where lama, kukui, and other tree species were also more common. 'Ahakea trees were found near (within 35 m) lama in 14.7% of the transect segments in Area I. This kipuka has the most biologically diverse forest on Hōlei and Poliokeawe Pali, and its substrates include the most weathered and oldest in appearance of the study area. Any future management efforts to encourage reproduction of the 'ahakea population should be initiated in Area I.

In his survey of Kealakomo, Warshauer (1974) found a total of 67 'ahakea trees on Holei Pali: 41 trees in Area I, 9 in Area II, and 17 in Area III at the hairpin turn in the Chain of Craters Road. He noted no regeneration of the species. During a study of rare species phenology, Zimmer (1982) found only 17 specimens of 'ahakea in Areas I and III combined, but, like Warshauer, he located nine in Area II. Since 1974, the

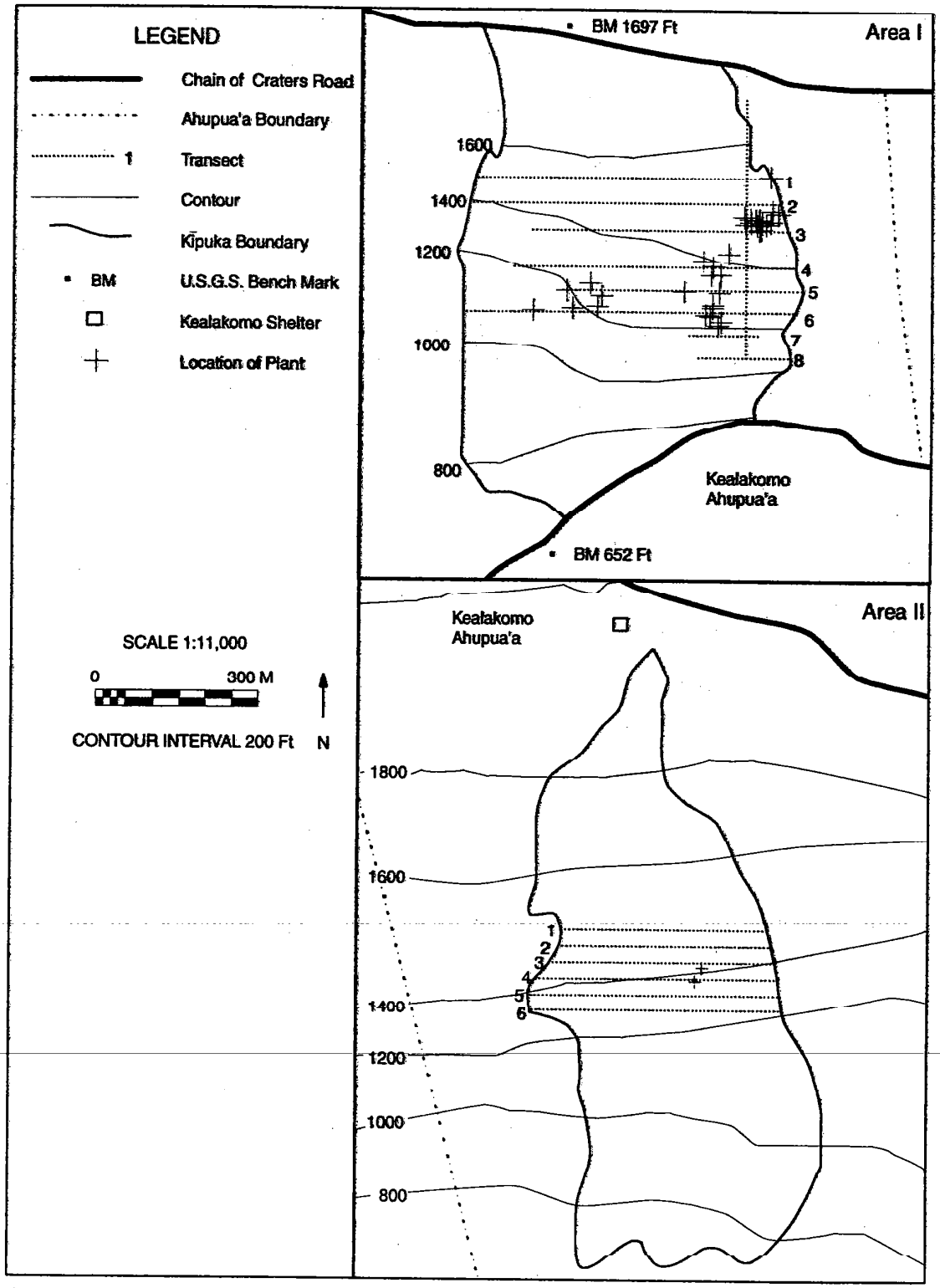


Figure 8. Distribution of `ahakea (Bobea timonioides) in Areas I and II on Hōlei Pali.

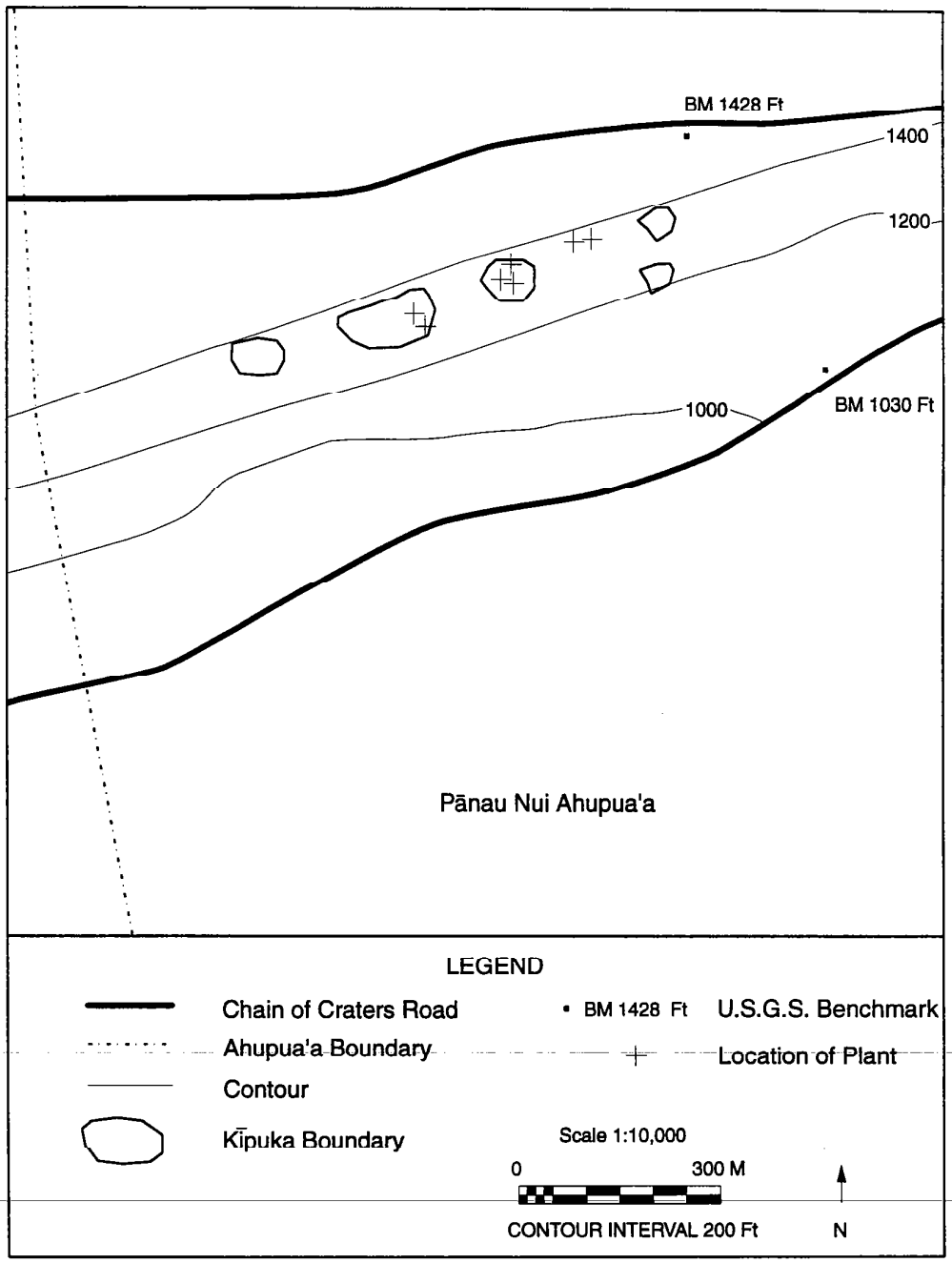


Figure 9. Distribution of `ahakea (Bobea timonioides) in Area III on Hōlei Pali.

'ahakea population has decreased by four trees in Area I, seven trees in Area II, and ten trees in Area III. Most of the Area I 'ahakea trees have survived the last 20 years, but six standing dead trees (recognizable by their distinctive pale bark) were seen in the kipuka during the 1993 survey. The Area II kipuka has lost most of its 'ahakea individuals since 1983. The five small kipuka of Area III have also lost more than half of the 'ahakea counted in 1974, and the poor condition of many remaining trees in 1993 indicates that more may soon die.

Earlier references to 'ahakea in Hawaii Volcanoes National Park include specimens in the Park Herbarium and checklists from the 1950s and 1960s. The species was collected at 488-518 m (1,600-1,700 ft) elevation in Kealakomo or Nāulu Forest at least three times in 1943, and was variously described as rare, infrequent, or frequent on the specimen labels. In his 1959 survey of the Kalapana Extension, Stone noted 'ahakea on cliffs of Kealakomo but did not comment on its abundance. Fosberg listed the species as frequent in Nāulu Forest in his 1966 Park checklist. Later collections of 'ahakea from the 1970s were all from Nāulu Forest kipuka on Hōlei Pali. One of these specimen labels (Clarke 54) noted fresh goat droppings near the tree in 1978.

While most reports of 'ahakea in the Park have focused on Nāulu Forest and Hōlei Pali, the species is also known from sites east and north of the study area. Warshauer and Jacobi (1973) found more than 100 'ahakea trees on an 'a'ā flow upslope of Kamoamoa east of Nāulu; it was at this site that Warshauer observed natural reproduction of 'ahakea (Warshauer 1974). The current condition of the Kamoamoa forest is uncertain, as Pu'u 'O'o lava flows and lava-generated fires have recently impacted this region. A botanical survey of the Park's East Rift in 1988 noted 'ahakea in wet forests above 305 m (1,000 ft) elevation; some mature 'ahakea trees appeared to have been killed by volcanic fumes from Pu'u 'O'o (Anderson et al. 1988). Outside Hawaii Volcanoes National Park, this species of 'ahakea is legally protected only in the tiny Keauohana Forest Reserve of Puna and in Manukā Natural Area Reserve of South Kona and Ka'ū. The species was also found during a survey of Wao Kele o Puna Natural Area Reserve (Char and Lamoureux 1985), but this area was subsequently exchanged for private land and has been slated for geothermal development.

Rare Plant Species

Hawaii Volcanoes National Park contains more than 50 native plant species that are unnaturally rare within the Park (National Park Service 1996); some of these were formerly candidates for endangered species status, and others are rare because of past disturbance to their habitat. Seven rare native plant species were found in Areas I-IV and Poliokeawe Pali in 1993-95; their numbers are summarized in Table 1.

Hame (Antidesma pulvinatum) - Hame or mehame, a tree of the Spurge Family (Euphorbiaceae), is an occasional component of lowland dry to mesic forest on the islands of O'ahu, Moloka'i, Maui, and Hawai'i (Wagner et al. 1990). On Hawai'i Island, hame

is seen most often in South Kona and Ka'ū Districts and is rare in Puna. A small to medium-size tree, hame has pointed ovate leaves with prominent veins. Hame flowers are small and unisexual, with the two sexes borne on different plants. Female trees bear flattened red to purple fruits.

Hame is extremely rare in Hawaii Volcanoes National Park. Only two trees are known to occur in the Park; these are in the Nāulu Forest kipuka designated here as Area I (Fig. 10). One tree was 5 m tall and in good condition in 1993, and the other was 13 m tall and in poor condition with leaves exhibiting sulfur dioxide fume damage. Both were adult trees; their mean dbh was 13.0 cm. Neither tree was in flower or fruit during June, and no reproduction was observed. Insect damage was light on the foliage of both trees. The 13-m-tall tree also had old damage to its base, probably from goats. Three alien species were found associated with the two hame trees (Fig. 7); these were the same common species seen near 'ahakea and hala pepe plants (lantana, scaly swordfern, and Natal redtop).

Warshauer (1974) observed only one hame tree 75 m west of the lava near the edge of the eastern Nāulu kipuka (Area I) along Hōlei Pali. This tree, growing with kukui, lama, and 'ahakea in 1974, is undoubtedly one of those found during the 1993 survey. Zimmer (1982) reported three hame trees in the Nāulu Forest within two separate kipuka of Hōlei Pali. One of these, the westernmost individual in the kipuka we designated Area II, was not found in 1993 and may have died in the last decade.

Several plantings of hame have been reported within Hawaii Volcanoes National Park. Thirty-three hame were planted at Nāmakani Paio, Kipuka Puaulu, Kipuka Nēnē, and Hilina Pali in 1957-58. By 1961, only two survivors at Nāmakani Paio and six at Kipuka Puaulu remained (Morris 1967). During the 1970s, 25 hame seedlings were planted at "various areas in the Park"; all were subsequently removed or died (Zimmer 1982). No planted hame trees are currently known within the Park.

Stone (1959) listed hame only from Nāulu during his survey of the Kalapana Extension. In his Park checklist, Fosberg (1966) also reported the tree restricted to Nāulu. The three specimens of hame in the Park Herbarium date from 1943 or 1978 and were all from Hōlei Pali; the 1978 collections were from the Nāulu Forest kipuka that we designated Area I (Clarke 102, Hoshide and Clarke 58). It is unlikely that future surveys will reveal additional hame within the Park. Because of extremely low numbers, lack of reproduction, and dioecius habit, the natural population of hame may have to be augmented by propagation and outplanting, if the species is to be retained as part of the Park's flora.

Naio (Myoporum sandwicense) - Naio is occasional to common in dry forest and on 'a'ā lava from the coast to high elevation on all the main Hawaiian Islands (Wagner et al. 1990). Relatively common on the island of Hawai'i, naio is a component of coastal strand, both lowland and montane forests, and subalpine communities. The species ranges

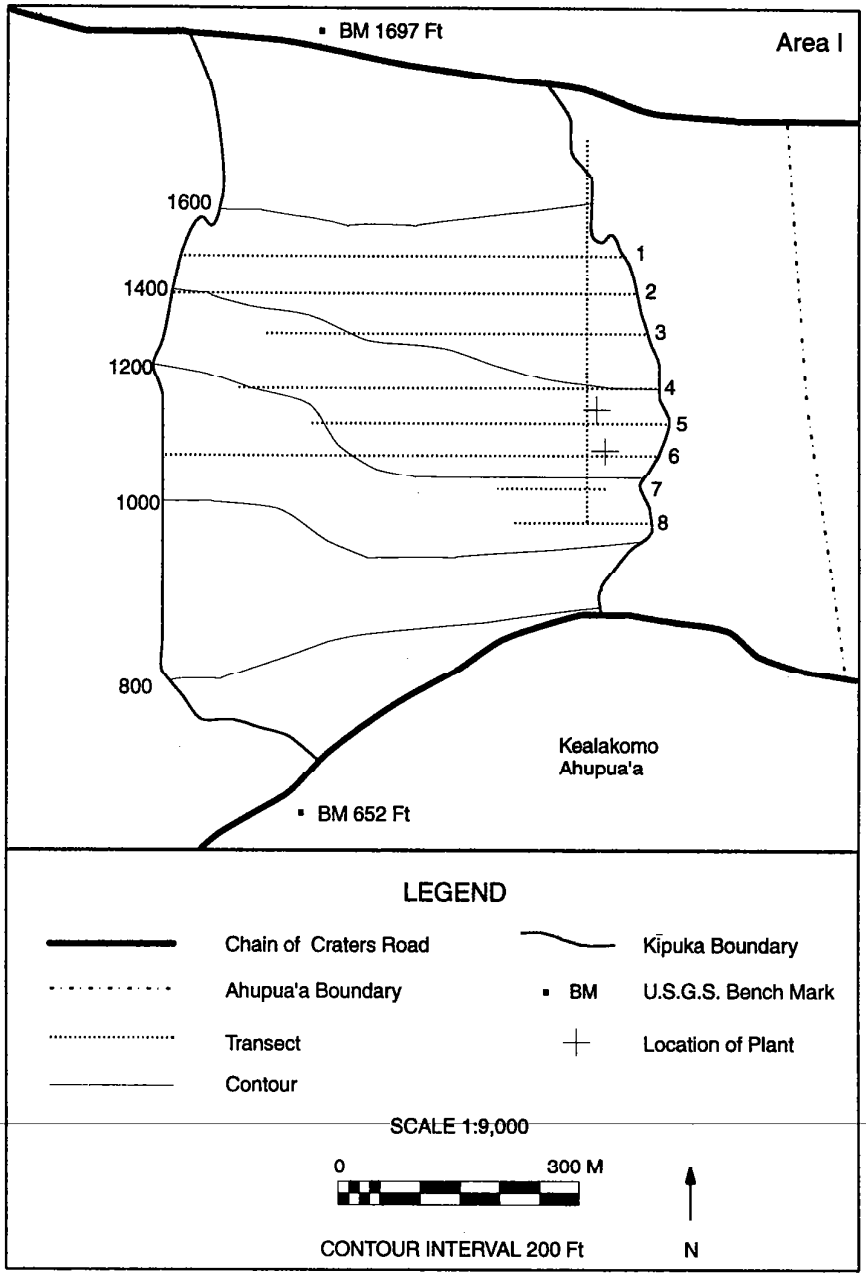


Figure 10. Distribution of hame (Antidesma pulvinatum) in Area I on Hōlei Pali.

in the Park from the coast to Mauna Loa near 2,130 m (7,000 ft) elevation but is uncommon, possibly because of the past impact of feral goats and domestic cattle on its habitat. A shrub or tree in the Myoporum Family (Myoporaceae), naio has narrow, shiny leaves, toothed when young; small, white to pink, tubular flowers; and white, berry-like fruit. Sometimes called bastard sandalwood, the wood of naio was formerly used as a substitute for the more valuable 'iliahi or true sandalwood (Rock 1974).

Naio was found in both Areas I and II, but was much more abundant in the Area II kipuka. Therefore, it was treated as a rare plant in Area I, where 47 individuals were mapped, but was surveyed as a common native tree species in Area II, which had 236 individuals along transects and an undetermined number off-transect. The naio of Area II were found most often in open shrublands along the edges of the forested kipuka. Naio was distributed primarily on the upper eastern edge of the Area I kipuka (Fig. 11). In this kipuka, the mean height of naio was 2.1 m, and the mean dbh for 12 individuals was 4.8 cm (Fig. 5 and 6). The remaining 35 trees were less than 1 cm dbh (or could not be measured at breast height); their mean basal diameter was 8.6 cm. Several large old naio trees were nearly prostrate, with basal diameters of 29-35 cm.

Seventy-six percent of the naio in Area I had flowers, and 72% bore fruit during June, 1993. Less than 5% displayed past goat damage, and insect damage to foliage was very light. Overall condition of the trees was good. For both Area I and II, reproduction appeared to be occurring, as more than 150 plants 2 m or less in height were found. Seven alien plant species were found near the 47 naio in Area I (Fig. 7). Lantana and Natal redtop were seen at most naio, and scaly swordfern occurred near more than 40% of the trees.

Naio was not noted in the small forest fragments within the hairpin curve of the Chain of Craters Road (Area III). The species has apparently disappeared from these tiny kipuka in the last 20 years, as Warshauer sighted one naio tree here in 1974. Naio was also rare in the Area IV kipuka west of Area II in 1995. Several trees were growing at the southern end of the kipuka near the top of Hōlei Pali, but naio was not seen elsewhere in this large forested kipuka.

Warshauer (1974) did not consider naio a rare plant during his survey of Kealakomo. He observed a few naio in the Nāulu Forest kipuka (Area I) and noted that naio was reproducing well in the next kipuka to the west (Area II). Zimmer (1983) observed high numbers of naio seedlings in the Kealakomo area and reported approximately 100 naio trees along Poliokeawe and Hōlei Pali from 'Āinahou Ranch to the hairpin curve in the Chain of Craters Road. He also recorded naio plantings made in 1974-76 at lower 'Āinahou (430 survivors), 'Āinahou house (46), Kipuka Nēnē (6) and Muliwai o Pele (12). No naio plantings were made in the vicinity of the present study (Morris 1967, Zimmer 1983). Older records of naio in the Hōlei Pali area include Stone's (1959) assessment of naio as scattered throughout the forest of upper Kealakomo around 460 m (1,500 ft) elevation. Fosberg (1966) listed naio as "very general" in Park forests

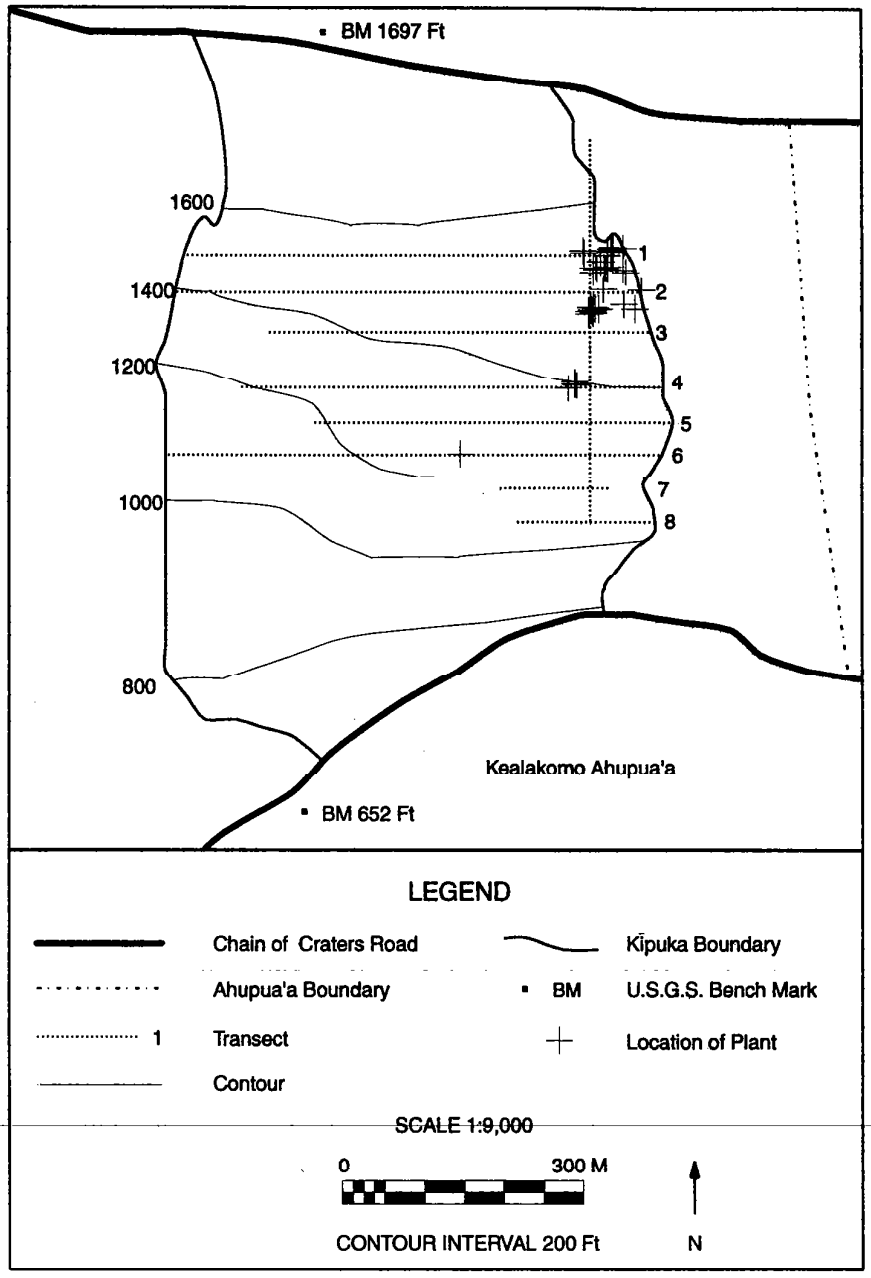


Figure 11. Distribution of naio (Myoporum sandwicense) in Area I on Hōlei Pali.

at 460-610 m (1,500-2,000 ft) elevation. The Park Herbarium contains 16 specimens of naio from Hawaii Volcanoes National Park, but only five of these were from Hōlei Pali, Kealakomo, or Nāulu Forest, collected between 1943 and 1993.

Hao (Rauvolfia sandwicensis) - Hao, a tree in the Dogbane Family (Apocynaceae), occurs in mesic forest and low-elevation remnant dry forest or shrubland on all the main Hawaiian Islands except Kaho'olawe. The tree is also known from lowland lava flows on Maui and Hawai'i (Wagner et al. 1990). Formerly, there were thought to be seven endemic Hawaiian species in the genus Rauvolfia (Sherff 1947); one of these, R. remotiflora, was limited to Hawai'i Island and was a candidate for endangered species status (U. S. Fish and Wildlife Service 1980). Today, only one variable species of Rauvolfia is recognized in Hawai'i (Wagner et al. 1990). Although widespread on several islands, hao appears to be relatively rare on Hawai'i Island, where it occurs in windward Kohala, near South Point, and within Hawaii Volcanoes National Park.

When surveyed in 1993, there were 26 hao trees in Area I, none in Area II, and only one in Area III (Fig. 12). With the exception of a few large 'ōhi'a lehua, hao were the largest trees found in the kipuka with a mean height of 10 m and mean dbh of 34.3 cm (Fig. 5 and 6); one large tree leaning outward over the cliff was measured at the base (29.0 cm). Regeneration of hao appeared to be poor, as no plants under 4 m in height were found during this survey. The smallest trees were at a very steep site within a kukui grove on the eastern side of the Nāulu Forest kipuka (Area I). This site also had at least six large, dead hao trees that had previously toppled over. Hao seedlings have been observed in the Area I kipuka in the recent past (ca. 1986).

Most hao trees (96%) bore flowers in June, but few were observed with fruit. Old damage to the bark, probably due to goats, was seen on 59% of the hao. Longlegged ants (Anoplolepis longipes) were observed on many hao trees. These ants may be attracted to insect prey utilizing hao, such as scale insects or aphids, and may possibly be beneficial to the trees (D. Foote, pers. comm.). Four alien plant species were found near the 27 hao trees (Fig. 7). Lantana and Natal redtop were seen near most hao trees, and scaly swordfern occurred at 40% of the hao sites.

Hao was found near (≤30m) lama in 10% of the transect segments of Area I. In this kipuka, hao had a population distribution pattern similar to that of 'ahakea (Fig. 8). Seven hao (27%) were growing in or near the same 10-m transect interval as 'ahakea trees (16 individuals). However, a multiresponse permutation procedure (Biondini et al. 1988) performed with BLOSSOM statistical software (Slausen et al. 1994) indicated that the two tree species were geographically separate ($p = 0.002$), each species growing in a clumped distribution.

Warshauer (1974) found 25-30 hao in Area I, one east of Nāulu Forest across the lava flow (in Area III), and four more east of the hairpin curve in the Chain of Craters Road. He also reported hao on Poliokeawe Pali, where no hao trees were found in 1993.

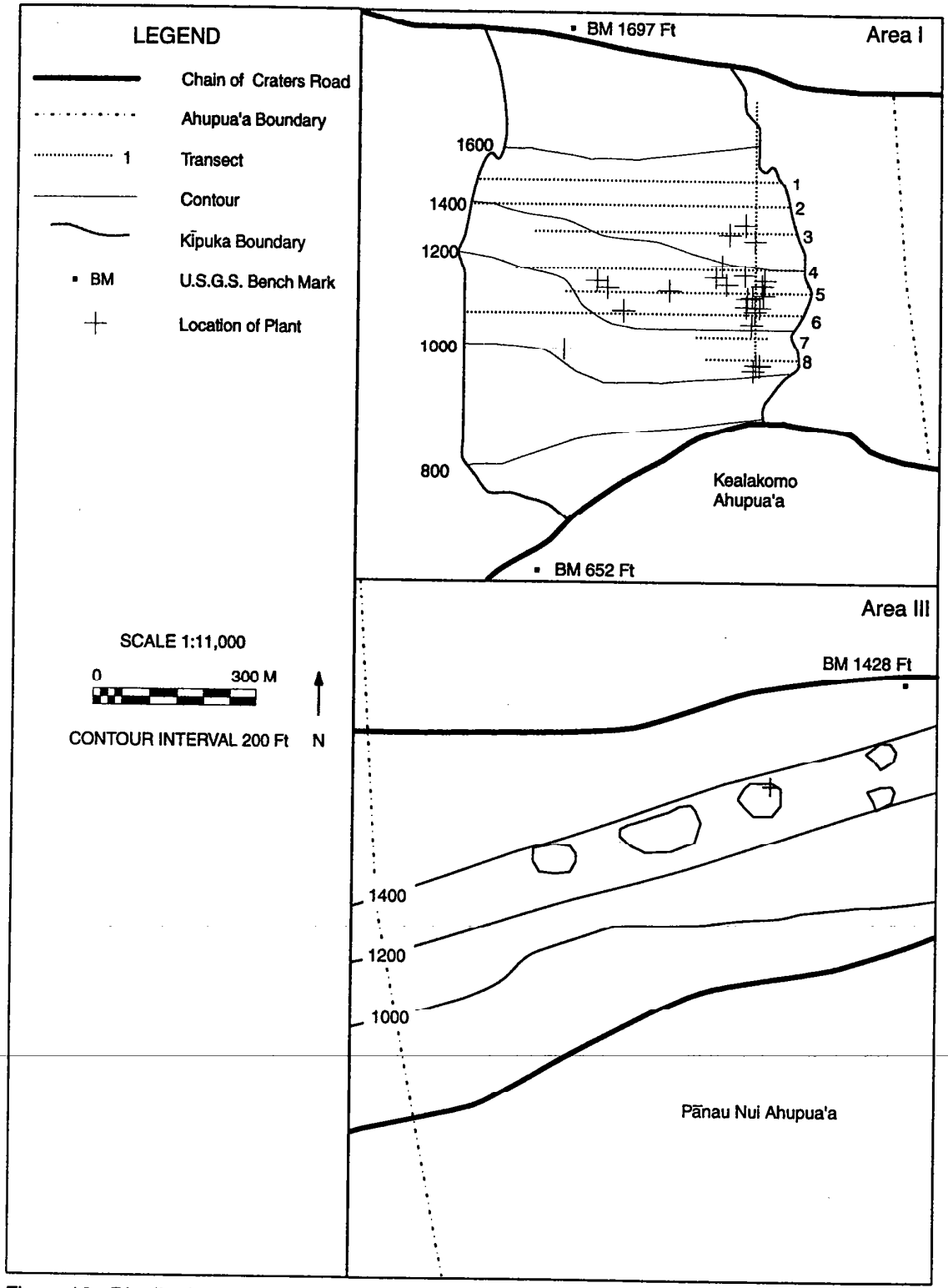


Figure 12. Distribution of hao (Rauvolfia sandwicensis) in Areas I and III on Hōlei Pali.

Zimmer (1983) observed 17 hao in the first three kipuka west of the Chain of Craters Road hairpin curve (Areas I, II, and III) at 300-490 m (1,000-1,600 ft) elevation. The population of hao in the Nāulu area has remained stable at 25 to 30 trees since 1974, but the species may have disappeared from Poliokeawe Pali in the last 20 years.

Park Herbarium specimens and earlier checklists indicate that Nāulu Forest, Kealakomo, Poliokeawe Pali, and Waha'ula have been the primary sites of hao distribution within Hawaii Volcanoes National Park. Stone (1959) listed hao as sparse along the pali of Kealakomo. Fosberg (1966) reported that hao was infrequent on Poliokeawe Pali. Older herbarium specimens are from Poliokeawe Pali (Fagerlund and Mitchell 546, 1943; Smathers sn, 1963). Only two relatively recent collections of hao came from Nāulu Forest (Clarke 53, 1978; Cuddihy 2199, 1988). Some former hao habitat in the Park has been destroyed by recent lava flows. Two fifty-year-old specimens in the Park Herbarium are from a site at 150 m (500 ft) elevation in Kealakomo and from a small pali in Pānau Nui north of Ka'ena Point; both sites were covered by Mauna Ulu lavas in 1971-72. Hao trees also grew at Waha'ula (Zimmer 1983), a site covered by lava in 1989. Outplanting of hao was done at Waha'ula in 1975 (Zimmer 1983), and at Hilina Pali, Nāmakani Paio, and Kipuka Puaulu in the 1950s (Morris 1967). Apparently none of these planted individuals survive today.

'Ohe (Reynoldsia sandwicensis) - A small to medium-size tree in the Ginseng Family (Araliaceae), 'ohe (also called 'ohe makai) occurs in lowland dry to mesic forests on all the main Hawaiian Islands except Kaua'i and Kaho'olawe (Wagner et al. 1990). A drought-deciduous species with shiny, yellow-green, compound leaves, 'ohe bears large clusters of small, greenish flowers followed by globose red to purple fruits. With its attractive foliage and fleshy, reddish bark, 'ohe is a very ornamental native species. Previously, eight different types of 'ohe were recognized (Sherff 1952), but these were combined into one species in 1980 (St. John 1980). 'Ohe was formerly a candidate for endangered species status (U. S. Fish and Wildlife Service 1980), but was subsequently determined too common to list as endangered. Although 'ohe is widely distributed throughout the islands, most of its lowland habitat has been developed for residences or agriculture, and it is rare on Hawai'i Island.

One 'ohe was found in the Area II kipuka on Hōlei Pali, and two were seen on Poliokeawe Pali (Fig. 13). The trees on the face of Poliokeawe Pali were in highly degraded, primarily alien vegetation; one of them grew in a clump of kukui trees. The mean height of these three mature trees was 9.0 m (Fig. 5), and the dbh for the one tree from Area II was 22.1 cm. The diameters of the Poliokeawe Pali trees could not be measured because of their precarious position on the steep cliff. The trees were judged to be in good to fair condition, and all three bore flowers and fruit when visited in December and May. Five alien plant species were found at one or more of the 'ohe (Fig. 7); these were lantana, scaly swordfern, and the flammable grasses Natal redtop, molasses grass (Melinis minutiflora), and bush beardgrass (Schizachyrium condensatum). Warshauer (1974) found six 'ohe along Hōlei Pali east of the Chain of Craters Road

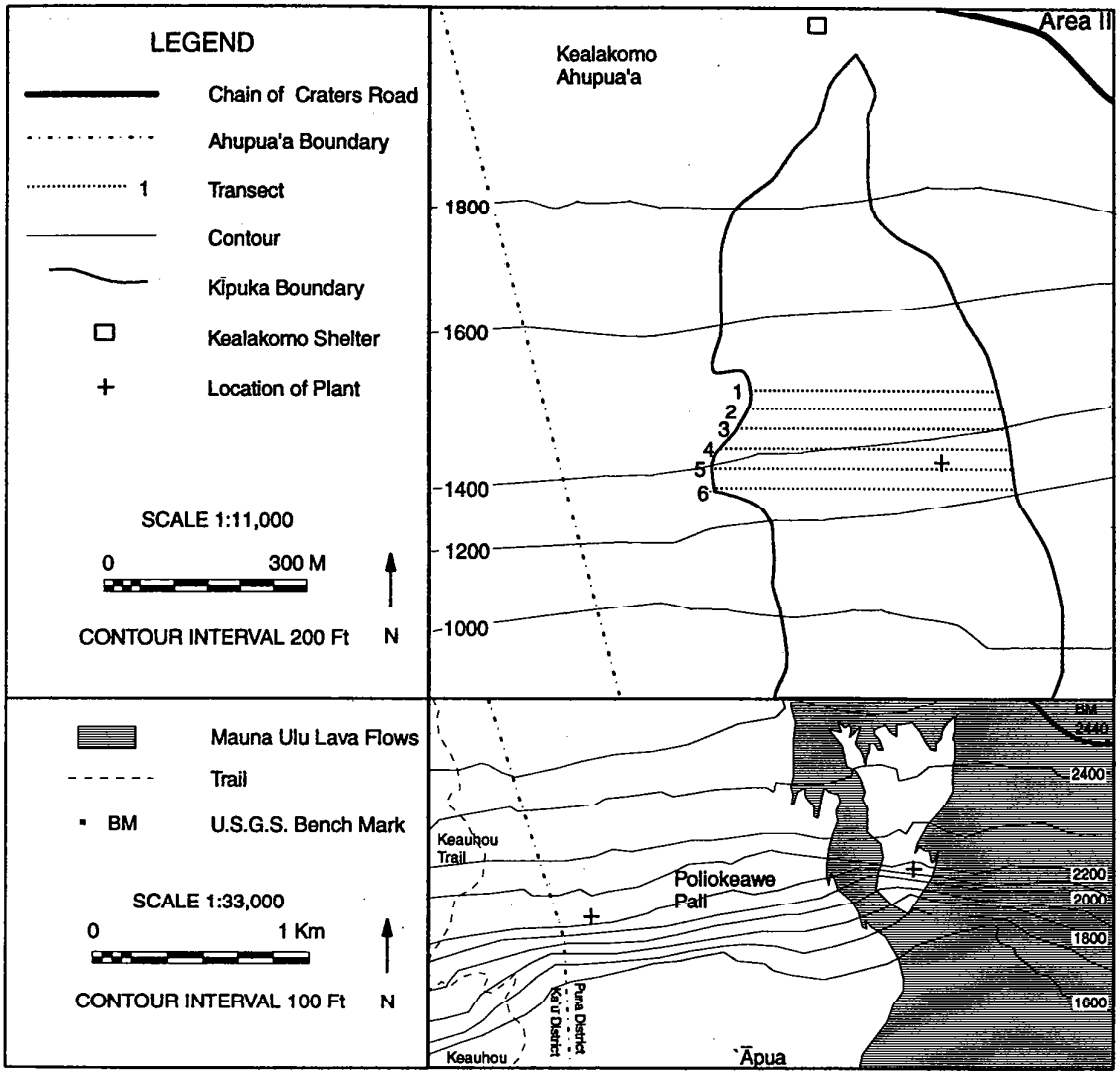


Figure 13. Distribution of `ohe (Reynoldsia sandwicensis) in Area II on Hōlei Pali and on Poliokeawe Pali.

hairpin curve, as well as several trees on Poliokeawe Pali. Zimmer (1982) noted only one tree on Poliokeawe Pali near the Puna/Ka'ū District boundary, just east of 'Āinahou Ranch. This tree, the westernmost individual in the current study area (Fig. 13), was still alive in 1993. The six trees seen by Warshauer 20 years ago were east of the current study are in vegetation that burned in 1992 (Tunison et al. in prep.), and the status of 'ohe there is unknown. Within the study area, 'ohe remains extremely rare, but stable.

Both Warshauer (1974) and Zimmer (1982) listed additional localities of 'ohe outside the current study area. Warshauer reported one tree on Hilina Pali, a few on Paliuli Pali, and at least 150 'ohe on 'a'ā upslope of Kamoamoa (an area proposed as a Special Ecological Area). This latter site was the only place he observed 'ohe reproduction. Zimmer listed two 'ohe trees on Paliuli and one tree at Waha'ula, as well as many trees outside and east of the Park. Since these surveys, Waha'ula and most of Paliuli Pali have been covered by lava, and the area upslope of Kamoamoa has been isolated into a kipuka and partially burned. The status of 'ohe there is uncertain while the eruption continues, but at least a few 'ohe persisted in 1995.

'Ohe has apparently never been common in Hawaii Volcanoes. Both Stone (1959) and Fosberg (1966) listed the species as rare in dry lowlands. Only one specimen was preserved in the Park Herbarium; this was collected on the side of Poliokeawe Pali ('Āpua ahupua'a) in 1943. The specimen label recorded "several trees to 40 ft high." The species has not been the focus of Park planting efforts (Morris 1967). Park records indicated only three 'ohe outplanted at Waha'ula (Zimmer 1982); these were subsequently destroyed by lava.

'Iliahi (Santalum paniculatum var. paniculatum) - This species of 'iliahi or sandalwood (Santalaceae) is restricted to Hawai'i Island, where it inhabits dry woodlands from the lowlands to the subalpine zone at 2,550 m (8,360 ft) elevation (Wagner et al. 1990). A partially parasitic shrub or small tree, 'iliahi has round to elliptic leaves, often yellow-orange or blue-green with pale undersides (Stemmermann 1980). The fragrant flowers of 'iliahi are small, four-parted, and greenish. The small, fleshy fruits are black, single-seeded drupes. Despite the loss of accessible lowland sandalwood trees during the 19th century sandalwood trade (Cuddihy and Stone 1990), the Hawai'i 'iliahi is not an endangered species. The species is locally common in only a few sites in Hawaii Volcanoes, possibly because its dry woodland habitat was heavily impacted by feral goats in the past.

One large 'iliahi tree was seen in Area I, and 29 'iliahi were found in Area II (Fig. 14). Most 'iliahi encountered in the Area II kipuka were relatively small, shrubby plants. Only five 'iliahi trees within the kipuka were >5 m in height. Mean 'iliahi height was 2.2 m (Fig. 5), and the mean dbh for 12 individuals was 10.4 cm (Fig. 6). The remaining 17 plants were <1 cm dbh, and had a mean basal diameter of 2.4 cm. While no young 'iliahi were found in Area I, reproduction was occurring in Area II with most plants (21) 2 m or less in height. More than half (58.6%) of the Area II 'iliahi were flowering, and

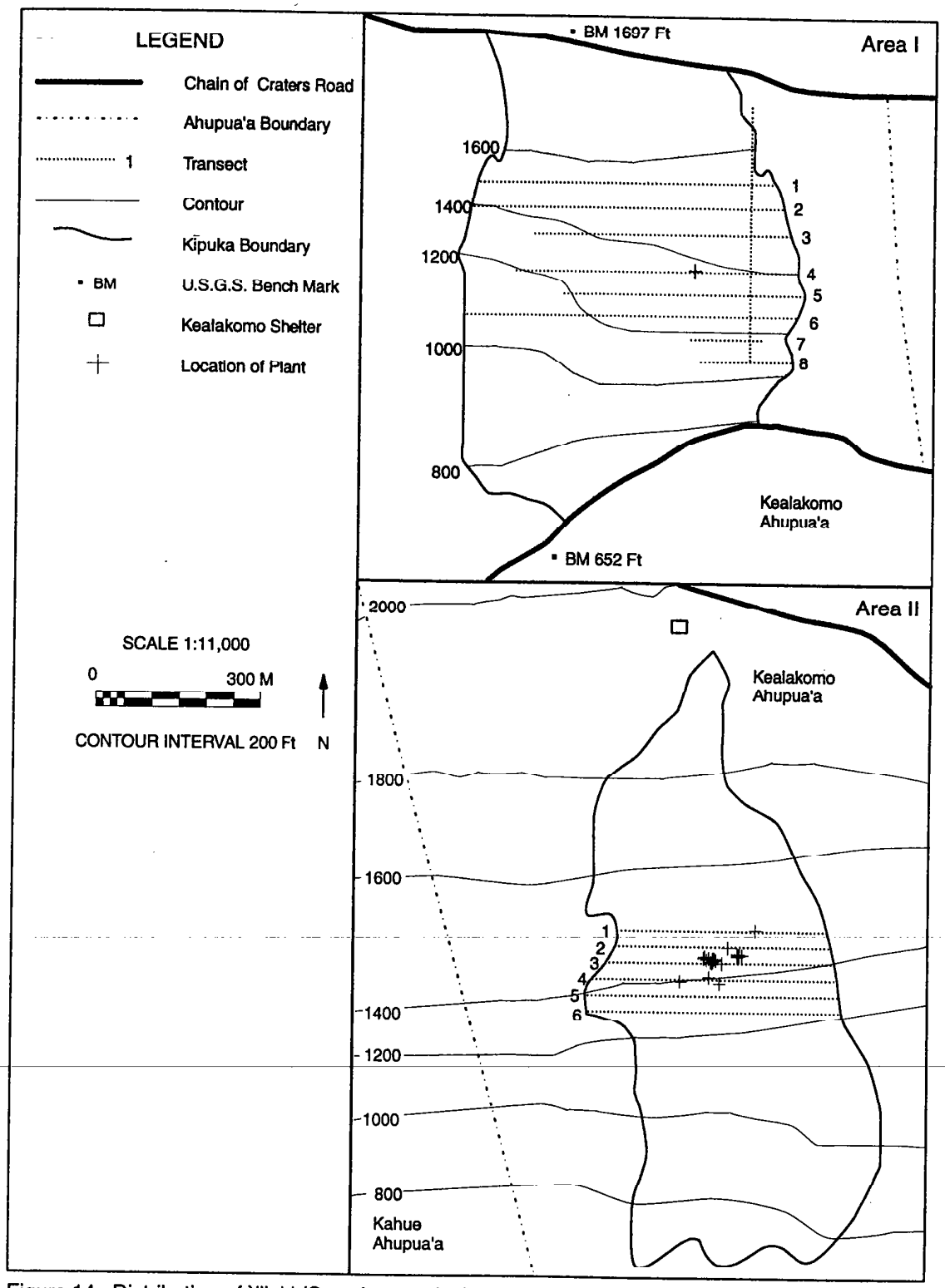


Figure 14. Distribution of `iliahi (Santalum paniculatum) in Areas I and II on Hōlei Pali.

10% bore fruit during the November-December survey. There was no goat or rat damage visible, and insect damage to foliage was very light. The trees were in fair to good condition. Five alien plant species were found near 'iliahi plants in Area II (Fig. 7). Most 'iliahi had Natal redtop nearby, and about half grew with broomsedge (Andropogon virginicus) and lantana. Scaly swordfern and bush beardgrass were seen near a few 'iliahi.

During his survey of Kealakomo, Warshauer (1974) saw only one 'iliahi in Area I, six in Area II, and two in Area III east of Nāulu Forest. He also noted two 'iliahi east of the hairpin curve, just outside the current study area. 'Iliahi appears to have increased in number in the Area II kipuka over the last 20 years, but has disappeared from the tiny kukui kipuka within the hairpin curve (Area III). Zimmer (1983) was unable to map 'iliahi on Hōlei Pali, but reported scattered small groups of trees north, west, and south of the hairpin curve of the Chain of Craters Road. Stone (1959) rated 'iliahi as uncommon in the Kealakomo/Pānau Nui sections of the Kalapana Extension. 'Iliahi is more common at other Park sites, including dry to mesic forests from Hilina Pali to 2,043 m (6,700 ft) elevation on Mauna Loa (Fosberg 1966). Numerous specimens of 'iliahi are held in the Park Herbarium, but only two are from Kealakomo or Poliokeawe Pali.

Many plantings of 'iliahi have been made within the Park. Morris (1967) recorded more than 150 'iliahi outplantings between 1924 and 1963, mostly in the Kilauea area; he was unable to estimate the survival rate. Zimmer (1983) reported a few plantings of 'iliahi in the 1970s, but none of these were in the study area. The nearest plantings of 'iliahi were along the Chain of Craters Road realignment at 'Āinahou.

Kolomona (Senna gaudichaudii) - Kolomona is a leguminous shrub indigenous to the main Hawaiian Islands and many other islands of the Pacific Basin. The species occurs primarily on talus slopes, lava flows, and rocky sites in dry to mesic forests of the leeward lowlands (Wagner et al. 1990). A relatively small shrub, kolomona has pinnately-compound leaves and open cup-shaped flowers of a pale yellow or greenish hue. Fruits are flat, dry pods. Although it is a widespread species found throughout the Pacific, kolomona is uncommon on Hawai'i Island, perhaps because little undisturbed lowland habitat remains.

Only one kolomona was found in the study area; this was in the Area I kipuka (Fig. 15), within the mixed dry forest of the pali. It was 1.2 m in height and had a basal diameter of 1.0 cm. The plant had no flowers or fruits in June, and no seedlings were observed. The kolomona was in fair condition with no goat or rat damage, and had light insect damage to its foliage. Three non-native species were growing near the kolomona: lantana, scaly swordfern, and Christmas berry (Schinus terebinthifolius) (Fig. 7).

Neither Warshauer (1974) nor Zimmer observed kolomona during their surveys of Hōlei and Poliokeawe Pali. Stone (1959) did not list the plant from the Kalapana Extension, and Fosberg (1966) did not include the species in his Park checklist. The Park

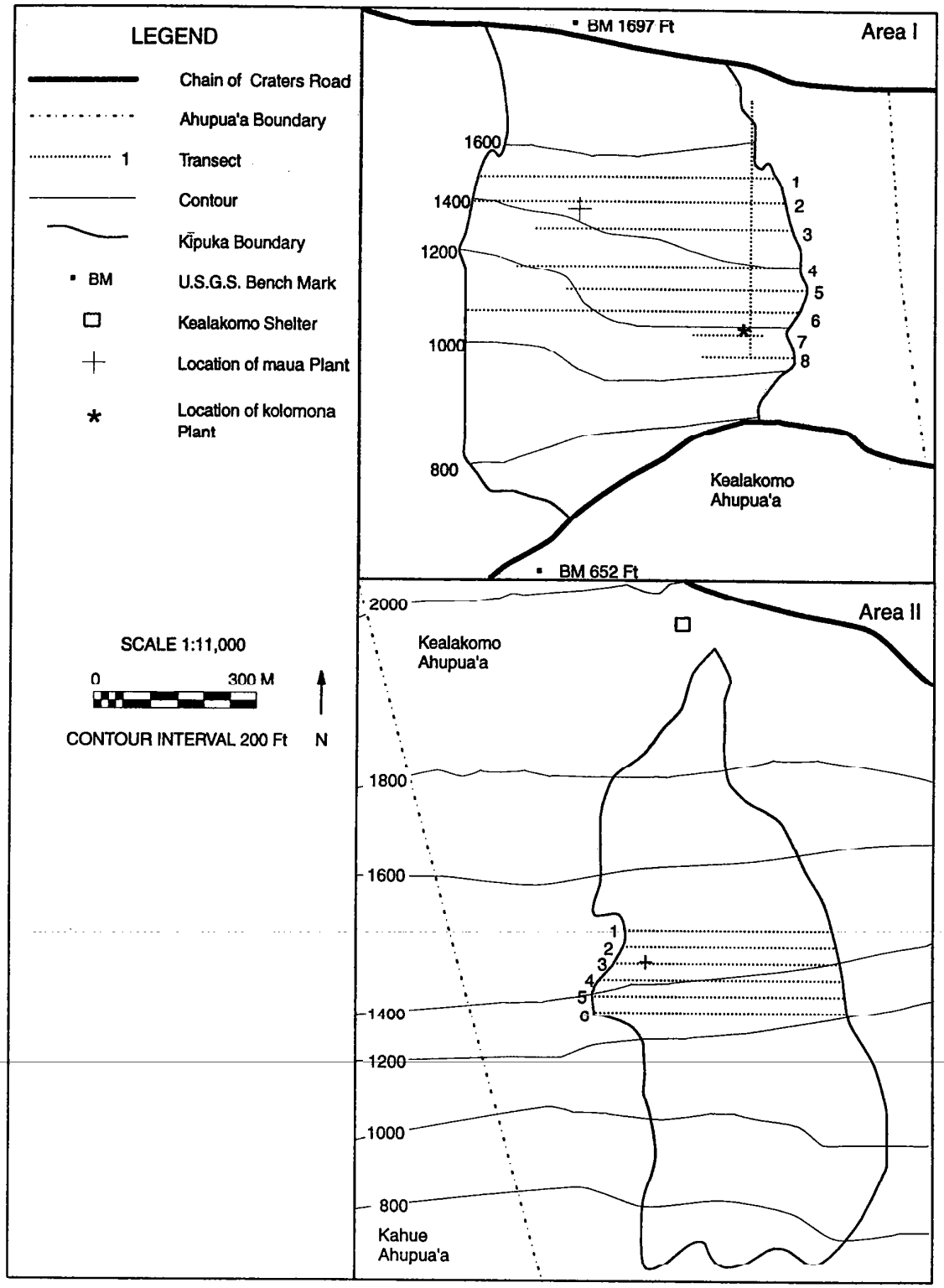


Figure 15. Distribution of kolomona (Senna gaudichaudii) and maua (Xylosma hawaiiense) in Areas I and II on Hōlei Pali.

Herbarium contains only one kolomona specimen (Cuddihy 1864) from the only other site known to support the species within the Park, an ʻaʻā flow above 60 m (200 ft) elevation in Kamoamoa ahupuaʻa (Warshauer and Jacobi 1973). Kolomona was still present as an uncommon shrub in Kamoamoa in 1988; this forest has not been intensively surveyed since lava flows of the current eruption separated the forest from the end of the Chain of Craters Road.

Maua (Xylosma hawaiiense) - Maua, a tree of the tropical Flacourtia Family (Flacourtiaceae), occurs in mesic forest, dry woodland, and occasionally in wet forest at low to middle elevations on all the main Hawaiian Islands except Niʻihau and Kahoʻolawe (Wagner et al. 1990). Formerly, maua was split into two species or varieties based on leaf characteristics, and the type on Hawaiʻi was called X. hillebrandii. A small to medium-sized tree, maua has glossy, toothed leaves and bears clusters of tiny, unisexual flowers followed by round, purple berries. In the past, maua was frequently seen in forests of Kaʻū District of Hawaiʻi Island (Rock 1974), but the species has become less common and is today rare in Hawaii Volcanoes National Park.

Three maua were observed in the study area in 1993: one in each of the Area I and II kipuka (Fig. 15), and one in Area IV between Poliokeawe and Hōlei Pali. (Fig. 16). The young tree in Area I was 3 m tall and in good condition. The maua in Area II was larger (10 m tall) and older, and was in fair condition with two dead branches. The tree in Area IV was found at the edge of a 1969 ʻaʻā flow and was 8 m tall with three separate trunks, each >35 cm dbh. None of the three trees bore flowers or fruit in June, November, or January, and none had goat or rat damage. Five alien plant species were found near maua trees (Fig. 7): lantana, scaly swordfern, guava (Psidium guajava), Natal redtop, and Christmas berry.

Warshauer (1974) noted one dying maua east of Area I across the lava flow (in Area III), one nearly-dead tree on lower Hōlei Pali in Area II, and one healthy tree between Hōlei Pali and Poliokeawe Pali next to an old ʻaʻā flow. It is possible the one nearly-dead specimen on lower Hōlei Pali in Area II improved in vigor and survived into 1993, but the dying maua tree east of Nāulu Forest across the lava flow was not seen during our survey of Area III and is presumed dead. Warshauer's one healthy maua tree between Hōlei and Poliokeawe Pali remained alive in 1993, but many of its branches have died.

Zimmer (1983) reported four maua trees in kipuka near the hairpin curve of the Chain of Craters Road, but it is not possible to compare his unmapped observations with our maua sightings. Maua has declined in the study area with the death of old trees, although the discovery of one young maua in the Area I kipuka was a hopeful sign. Stone (1959) reported maua as an infrequent tree along the pali of Kealakomo, and Fosberg (1966) listed maua as frequent in Nāulu and Kealakomo. The Park Herbarium contains only two specimens of maua from Nāulu Forest and Kealakomo collected in 1943 and 1959. A few plantings of maua were made in the Park in 1955 at Kipuka

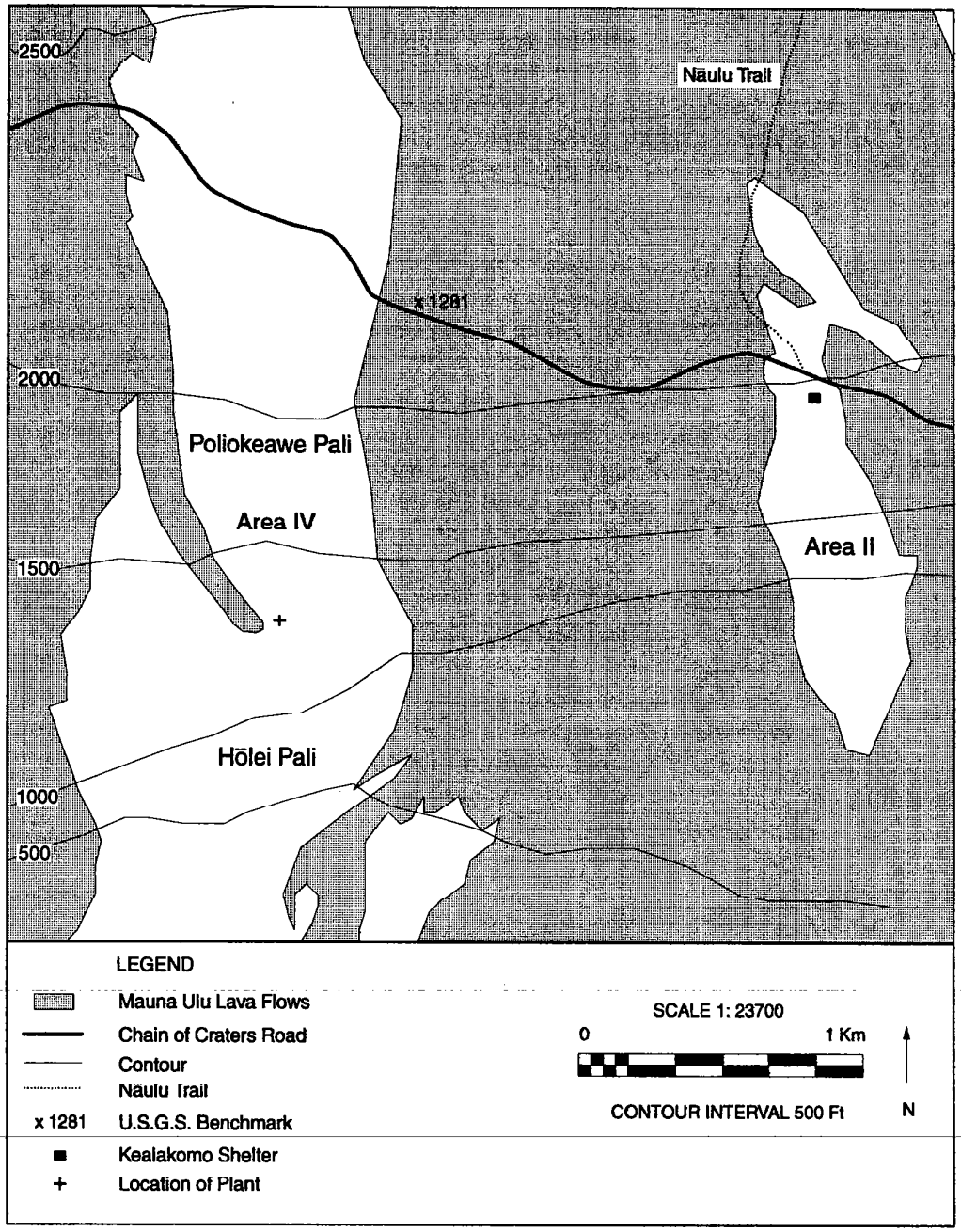


Figure 16. Distribution of maua (Xylosma hawaiiense) in Area IV between Hōlei and Poliokeawe Pali.

Puaulu and Park Headquarters (Morris 1967), but no outplanting was done near the study area. The maua population nearest the study area is in a forest on 'a'ā upslope of Kamoamoa, where Warshauer and Jacobi (1973) sighted three maua trees more than 20 years ago. Other Park sites supporting natural populations of maua are Kipuka Puaulu and 'Ola'a Forest, in mesic to wet forest at 1,220 m (4,000 ft) elevation (Pratt et al. in prep. a, Pratt and Abbott in prep.)

Historical Sightings of Rare Plants

Kauila (Alphitonia ponderosa) - A tree in the Buckthorn Family (Rhamnaceae) native to dry forests on all the main Hawaiian Islands, kauila was previously a candidate for endangered species status and was considered rare, depleted, and potentially endangered by Fosberg and Herbst (1975). Six mature kauila were seen on or near Hōlei and Poliokeawe Pali by Warshauer (1974). Zimmer (1982) also reported six kauila near Hōlei Pali, in addition to approximately 30 trees between Kipuka Nēnē and Hilina Pali (outside the current study area). Earlier, Stone (1959) rated kauila as "scattered and infrequent" in the upper Kealakomo forest, where he described kauila habitat as bare 'a'ā flows with 'ōhi'a lehua trees. Four kauila specimens in the Park Herbarium were collected in upper Kealakomo or on Poliokeawe Pali between 1943 and 1975.

Although several kauila sites mapped by Zimmer and described by Warshauer were searched in 1993, no kauila were found. Kauila may have disappeared from Hōlei and Poliokeawe Pali in the last ten years. More than a decade ago, Zimmer (1982) warned that molasses grass expansion in the area might inhibit kauila regeneration. Kauila may be a candidate for more intensive survey work and possible Park restoration efforts.

Kulu'i (Nototrichium sandwicense) - Kulu'i, a shrub in the Amaranth Family (Amaranthaceae), was not seen during this survey. Although distributed in lowlands on all the main Hawaiian Islands (Wagner et al. 1990), kulu'i is only locally common on Hawai'i Island. Within the Park, this species was known from only two localities: Poliokeawe Pali, where it was collected once in 1964 (Hamilton sn, HAVO Herbarium); and Hilina Pali, where one individual was reported in 1974 (Zimmer 1983). As kulu'i has not been found in the Park for more than 20 years, and most of its habitat has been covered by lava or burned, the shrub is presumably extinct within Hawaii Volcanoes. Kulu'i plants propagated from Ka'u material were planted at 'Āinahou in 1978, but subsequently died (Zimmer 1983).

Kōlea (Myrsine lanaiensis) - This species of kōlea, a member of the Myrsine Family (Myrsinaceae), is a tree native to leeward dry forests on most of the main Hawaiian Islands (Wagner et al. 1990). This kōlea formerly occurred infrequently in dry forests between 460 and 760 m (1,500-2,500 ft) elevation in the Park (Fosberg 1966). Stone (1959) found the dry-forest kōlea occasionally in the upper Kealakomo transition forest. After the lava flows of 1969-74 dissected the Nāulu Forest, Warshauer (1974)

found only one young kōlea tree in his study area ("above Nāulu Forest"). No kōlea trees were sighted in the surveyed kipuka of Poliokeawe or Hōlei Pali during 1993. Today, this species appears to be restricted in the Park to ʻĀinahou.

Spermolepis hawaiiensis - This listed endangered species is a small herb in the Parsley Family (Apiaceae); it was formerly found on most of the main Hawaiian Islands (Wagner et al. 1990). In 1943, Spermolepis was documented from Hawaii Volcanoes National Park, where it was collected in ʻōhiʻa lehua forest of ʻĀpua ahupuaʻa at 610 m (2,000 ft) elevation (Fagerlund and Mitchell 1942-47, Fosberg 1966). All that remains uncovered by recent lava flows in this area was searched in 1993 during a survey of Kipuka Kahaliʻi SEA, but Spermolepis was not found. The open forest upslope of Poliokeawe Pali has been altered by a deep layer of cinders that fell during the Mauna Ulu eruption of 1969-74, and Spermolepis hawaiiensis may have been extirpated from its former Park habitat.

Other Endemic Plants - Several native tree species and at least one herbaceous plant were formerly components of Nāulu Forest and vegetation on the adjacent pali before extensive lava flows of the Mauna Ulu eruption covered much of ʻĀpua, Kahue, and Kealakomo land divisions in 1969-74. ʻAiea (Nothocestrum breviflorum), now listed as an endangered species (U. S. Fish and Wildlife Service 1994b), was found in Nāulu Forest in 1943 (Fagerlund and Mitchell 1942-47, Fosberg 1966). This rare tree of the Nightshade Family (Solanaceae) was described as growing on an ʻaʻā flow at 520 m (1,700 ft) elevation in Kealakomo. Stone (1959) did not list ʻaiea in his survey of the Kalapana Extension.

Kōpiko (Psychotria hawaiiensis), manono (Hedyotis terminalis), and ʻohe (Tetraplasandra hawaiiensis) were also found in Nāulu Forest and Kealakomo in the 1940s (Fosberg 1966, Fagerlund and Mitchell 1942-47). The collection localities of these native trees were on ʻaʻā at 520-580 m (1,700-1,900 ft) elevation; this area is just upslope of the easternmost Nāulu Forest kipuka (Area I). Kōpiko and manono are still common trees in wet and mesic forests more than a mile above Nāulu, but are no longer present in the dry forest remnants. At least two individual ʻohe or Tetraplasandra trees survived the Mauna Ulu lava flows in a kipuka upslope of Nāulu Forest (Zimmer 1983), but their current status is uncertain.

Kūpala (Sicyos pachycarpus, formerly known as S. microcarpus) is an endemic herbaceous vine in the Squash Family (Cucurbitaceae). This vine, native to coastal and dry forest communities on the lower leeward slopes of all the main Hawaiian Islands (Wagner et al. 1990), was collected in ʻĀpua ahupuaʻa at 610 m (2,000 ft) elevation on the slope of the pali (presumably Poliokeawe) in 1943 (Fagerlund and Mitchell 1942-47, Fosberg 1966). Kūpala was not found in Kealakomo by Stone (1959) or Warshauer (1974) and may have been lost from the Park in the last 50 years.

Common Native Tree Species

Nineteen species of native shrubs and trees were found in Areas I and II during the 1993 survey (Appendix I). Four tree species were counted along transects; two were common in both kipuka, one was relatively uncommon, and one was found in only one kipuka.

Lama (Diospyros sandwicensis) - Lama was the most abundant tree species in Nāulu Forest, with an overall density of 125.6 plants/ha in the two kipuka. This tree was the canopy dominant in the most densely forested parts of the kipuka. The majority of lama trees were in the >5 m height class (93.8 plants/ha), but smaller size classes were also represented (Table 3). Lama was reproducing in the dry forests of Nāulu, although the number of plants/ha was very low in the seedling and sapling height classes of <1m and 1-2 m. The size-distribution of lama in both Areas I and II (Fig. 17) indicated a plant population composed primarily of old trees. With so few young plants, the lama population did not appear to be increasing, but may be maintaining itself. Reproduction of lama, a tree known to have a slow growth rate (Lamoureux et al. 1981), may have been interrupted by feral goats in the past; the low number of lama in the >3-5 m height class may be due to browsing that ceased approximately 20 years ago.

In a study of coastal woodlands east of Nāulu Forest, Williams (1990) observed lama density on pahoehoe substrates two to four times that of Nāulu Area II. Her study sites on 'a'ā had lama density more than 30 times greater than the current Nāulu study sites; most of the individuals she counted were seedlings. Most of Williams' 13 study sites with lama were much wetter than Nāulu Forest and were at lower elevations. In another study of dry forests that included a Park site at Kamoamoa about 9 km east of Nāulu, Stemmermann and Ihsle (1993) found the density of lama trees >2 cm in diameter was 20/100m^2 in an 'a'ā kipuka at 106 m (348 ft) elevation. This represents a lama density more than 15 times that found at Nāulu. Stemmermann and Ihsle investigated the species composition, structure, and water relations of dry forest species on substrates of various ages; they concluded that lama replaced 'ōhia lehua on older substrates and was a better competitor for limited water.

There were many more lama trees in Nāulu Area II than in the Area I kipuka, suggesting that the substrates of the western kipuka are more suitable to lama establishment. Williams (1990) found that lama densities were higher on 'a'ā than on pāhoehoe; she also observed that lama grew to larger size on 'a'ā substrates. Results of lama density comparisons in the current study support Williams observations; Area II, which had a greater number of lama trees, was predominantly 'a'ā, while Area I had more varied substrate of both 'a'ā and pāhoehoe (Holcomb 1987).

Alahe'e (Canthium odoratum) - Alahe'e, the most common understory tree of the kipuka, was too abundant to count along transects in Area I, but density and size class data were collected Area II. Although the total number of alahe'e plants/ha was low in

Table 3. Density (Number of Plants/ha) of Four Common Native Tree Species in Areas I and II Combined[1].

Species	Number of Plants/ha Height Class (m) <1	1-2	>2-3	>3-5	>5	Total
Canthium odoratum[2] Alahe'e	6.6	18.4	0.8	1.6	1.2	28.7
Diospyros sandwicensis Lama	7.8	8.5	3.3	12.2	93.8	125.6
Myoporum sandwicense Naio	7.3	20.3	14.9	8.5	0.4	51.4
Sophora chrysophylla Mamane	0.7	2.2	2.5	0.0	0.0	5.4

[1] Calculated from the total number of trees of each species counted within all 10-m intervals of the belt transects in both Area 1 (3.07 ha) and Area II (2.44 ha)

[2] For Area II only

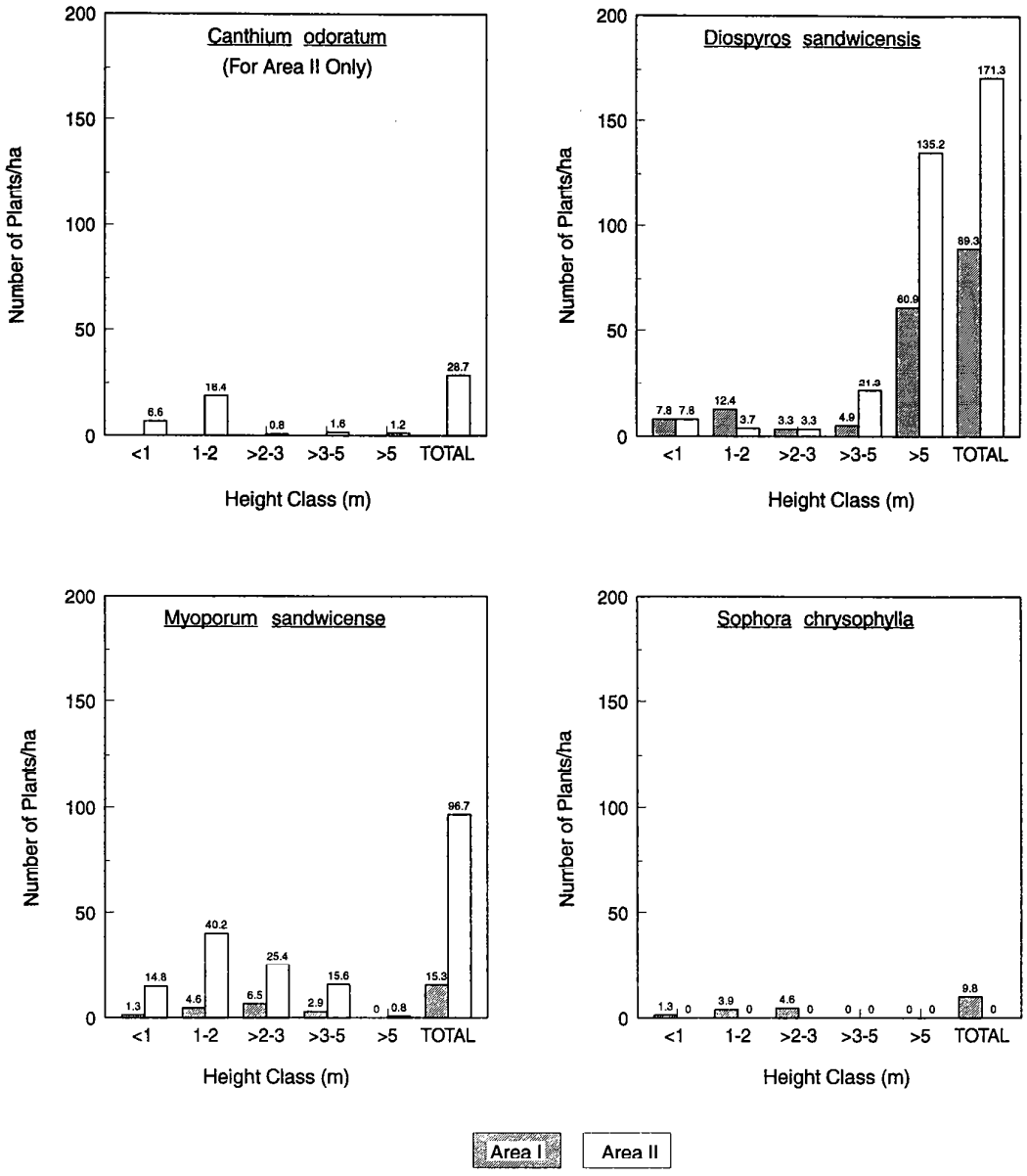


Figure 17. Height class distribution of four common native tree species in Areas I and II on Hōlei Pali.

the Area II kipuka (28.7/ha), the sapling and young tree size class (1-2 m) was well represented (Table 3). This size-distribution skewed to the young classes indicates a growing population that may attain stability when more individuals mature (Fig. 17). Alahe'e may be recovering from past depredations of feral goats in the Nāulu kipuka.

At her study sites to the east, Williams (1990) found alahe'e densities vastly greater than those at Nāulu; she observed densities of alahe'e seedlings and young trees of 2,000/1,000 m^2 on 'a'ā substrates and approximately 1,000/1,000 m^2 on pāhoehoe. Stemmermann and Ihsle (1993) also measured greater alahe'e density at their Kamoamoa dry forest site; counting only trees >2 cm diameter, they found 33 alahe'e/100 m^2. In the current study, alahe'e was far more abundant in the Area I kipuka. Alahe'e was not sampled in this kipuka, but alahe'e density here may have been comparable to the wetter, more eastern sites of Williams. Because native tree density values in the Nāulu kipuka were so different from those found elsewhere in the Park by other researchers, it might be useful to establish permanent vegetation plots in Nāulu to evaluate forest structure.

Naio (Myoporum sandwicense) - Naio was relatively rare in Area I with a density of only 15.3/ha, but the tree was more common in the understory of the Area II kipuka. Naio density in Area II was 96.7 plants/ha, and the size-distribution was that of a stable population with nearly equal seedling and mature tree height classes (Fig. 17). As with lama, the Area II kipuka seemed to provide more suitable habitat for naio than did Area I, perhaps because of its preponderance of 'a'ā substrates. Naio is somewhat fire-tolerant and capable of resprouting after low intensity fire, but the species is not known to be stimulated by fire (Smith and Tunison 1992). While some naio plants in the Area II kipuka may have survived past fires, it is unlikely that differences in the fire histories of the two kipuka explain differences in current naio abundance. Neither Williams (1990) nor Stemmermann and Ihsle (1993) observed naio in their Park lowland study sites.

Māmane (Sophora chrysophylla) - Māmane was uncommon in Area I with a total of only 9.8 plants/ha, and none was found in the Area II kipuka. Māmane trees were not evenly distributed throughout the kipuka, but were concentrated on its northeastern edge near the 1972 lava flow. The māmane population in the dry forest appeared to be very young; no plants >3 m in height were seen. Although rare, māmane seedlings and saplings were present (Fig. 17). Williams (1990) did not find māmane in her woodland study sites east of Nāulu Forest, and Stemmermann and Ihsle (1993) had no māmane in the Kamoamoa dry forest.

Māmane numbers may have been reduced in the Nāulu area when feral goats were abundant before the mid-1970s (Baker and Reeser 1972); it is less likely that māmane trees were lost to fire, as the species is fire-tolerant (Smith and Tunison 1992). Māmane trees in the Nāulu Forest kipuka (Area I) today may have grown from seeds in the soil seed bank; no evidence of post-fire stump-sprouting was noted. It is unlikely that existing māmane are the result of past planting programs; neither Morris (1967) nor Zimmer (1982-83) list māmane planting sites at Nāulu.

Alien Plant Species

Thirty-six alien or non-native species were encountered within the two large kipuka on Hōlei Pali (Areas I and II) (Appendix I); the frequency of 35 of these plants was recorded on transects and at rare native tree sites. While today alien species comprise more than half the vascular flora of the Nāulu kipuka (Appendix II), it is possible that few of these alien plant species were present 50 years ago. Fagerlund and Mitchell noted only one non-native plant (Stachytarpheta sp.) during collecting forays to the Nāulu Forest area in 1943. The most invasive alien plant species of the study area were a fern, four grasses, and four shrubs (Fig. 18). Firetree or faya (Myrica faya) did not occur within the surveyed portions of the two primary Nāulu kipuka, but scattered individuals were seen in the forest of Area IV between the two pali, and the tree is common in the upper part of this kipuka. The study areas are just downslope of the lower distributional range of this highly invasive tree (Camrath and Tunison in prep.).

Scaly Swordfern (Nephrolepis multiflora) - This alien swordfern occurred in over 80% of the 10-m transect intervals in both Areas I and II (Fig. 18) and had high estimated cover (5-25%), particularly along the edges of the kipuka. Scaly swordfern is a relatively recent arrival to Hawai'i (Wagner 1950), but has become a common ground cover in lowland mesic forests, as well as in East Rift rain forests upslope of the study area (Pratt et al. in prep. b). Although abundant at some dry Park sites, scaly swordfern does not appear to be fire-adapted (Tunison et al. 1994).

Grasses - Natal redtop (Rhynchelytrum repens) occurred in over 90% of transect intervals in Areas I and II (Fig. 18) and was the most abundant alien grass species present, averaging 5-25% cover. Native to South Africa, Natal redtop was introduced as a pasture grass prior to 1900 and soon became naturalized in the dry lowlands (Whitney et al. 1964). Natal redtop was not listed in a 1959 survey of the Kalapana Extension (Stone 1959). Today Natal redtop is widespread in the Park and is the dominant or co-dominant grass in drier regions of the coastal lowlands (Mueller-Dombois 1980), where it has increased in cover following wildfires (Tunison et al. 1994).

Two American grasses, bush beardgrass (Schizachyrium condensatum) and broomsedge (Andropogon virginicus), were common at Nāulu, where each occurred in about half of the transect intervals (Fig. 18) and averaged 1-5% cover. Higher cover of broomsedge was noted on the kipuka edges, at the top of the study area, and on pāhoehoe substrates. Bush beardgrass was first collected in Hawaii Volcanoes in 1961, and subsequently spread throughout the Park's coastal lowlands and mid-elevation woodlands. Broomsedge first appeared in Hawai'i in 1925 (Wagner et al. 1990), but apparently did not invade Hawaii Volcanoes until the 1960s (Fosberg 1966). Neither grass was seen during a 1959 survey of the Kalapana Extension (Stone 1959). Native forests and woodlands invaded by these flammable and fire-tolerant grasses are susceptible to wildfire (Hughes et al. 1991, Tunison et al. 1994).

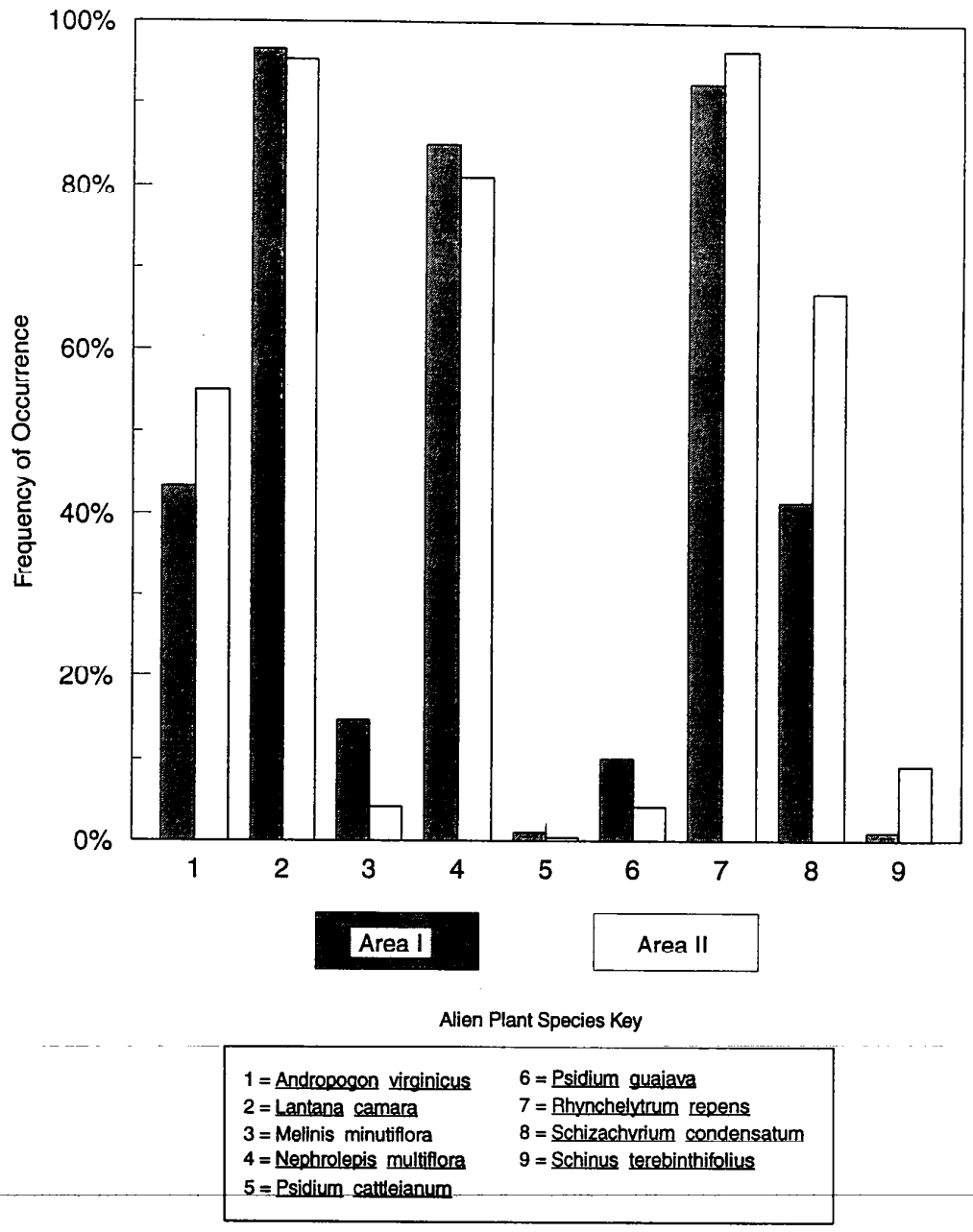


Figure 18. Frequency of occurrence of nine alien plant species in 10-m segments along transects in Area I and II on Hōlei Pali.

Molasses grass (Melinis minutiflora) was uncommon and scattered in distribution in the Nāulu Forest study area (Fig. 18); its cover was <1%. A large mat-forming grass native to Africa, molasses grass was introduced to the Hawaiian Islands in 1914 for use as cattle forage (Wagner et al. 1990), but has become one of Hawai'i's most serious pests (Smith 1985). Molasses grass was first noticed near Kilauea in 1940 and extended its range to Park roadsides and coastal grasslands in less than 10 years (Fagerlund 1947). Extremely flammable, molasses grass is highly fire-adapted and increases cover with each successive wildfire (Hughes et al. 1991). Once a dense cover of this grass develops in a native woodland, the eventual destruction of the native woody plants by fire is likely.

Shrubs - Lantana (Lantana camara) was the most abundant and widely distributed alien woody plant species in the study area, where it was found in >90% of transect intervals in Areas I and II (Fig. 18), with 5-25% estimated cover. Williams (1990) also found abundant lantana in her coastal woodland study sites east of Nāulu. She observed >250 lantana/1,000 m^2 on 'a'ā and chunky pāhoehoe substrates in both open and semi-open sites. Lantana has been in or near the study area for at least 50 years. Both Fagerlund (1947) and Stone (1959) cited Kahue land division, just west of Nāulu, as an area of lantana concentration. Lantana was introduced to Hawai'i as an ornamental in the mid-19th century (Wagner et al. 1990), but was soon recognized as a pest in pastures (Hosaka and Thistle 1954). The toxic lantana was an early target of biological control efforts; biocontrol was only partially successful at reducing the shrub and was most effective in open pastures (Clausen 1978). As lantana produces allelopathic substances and is capable of replacing native shrub and tree species (Smith 1985), it may be a serious threat to the endangered and rare plant species of Nāulu Forest.

Two species of guava (Psidium cattleianum and P. guajava) and Christmas berry (Schinus terebinthifolius) were uncommon in the study area, occurring in <10% of transect segments (Fig. 18). Each of these three shrubs generally had <1% estimated cover, with slightly higher estimates for common guava (1-5%) in the lower part of one kipuka. Both guavas were brought to Hawai'i as fruit trees around 1825 (Nagata 1985), but have subsequently invaded native forests. Christmas berry was introduced as an ornamental but has become a pest in moist lowland vegetation on most of the Hawaiian Islands (Wagner et al. 1990). The shrub is known to be allelopathic and may displace native plants (Smith 1985). All three species were more common in Williams' (1990) coastal woodland study sites east of Nāulu Forest, where strawberry guava displayed high densities in shaded sites and Christmas berry had many seedlings in open sites on pāhoehoe. Guavas do not appear to pose a great threat to native vegetation in the dry forests of Nāulu, which may not be preferred habitat for these two alien species. Christmas berry deserves monitoring attention and is a possible target for alien plant control at rare plant sites.

MANAGEMENT CONSIDERATIONS

The Nāulu forest remnants and native vegetation of Hōlei and Poliokeawe Pali are valuable as habitat for rare native plants, and they are also good examples of dry forest, a natural community that has almost vanished from the Hawaiian Islands. The following are suggestions for management and research to insure the survival of the Park's dry forest and its rare plants and to prevent further loss and degradation.

1) Lantana, Christmas berry, and molasses grass should be controlled in the most densely forested parts of the two main kipuka on Hōlei Pali. The species-rich lama and 'ohi'a lehua forests of Nāulu cover an area of less than 75 ha. Particularly noxious alien plants could be controlled throughout the two kipuka, or alien plants could be removed from the immediate vicinity of rare plants. Control throughout the kipuka would be the preferred alternative, if feasible. Small-scale herbicide tests may be required to find the most effective herbicide to use as a treatment for lantana. Several herbicide treatments for Christmas berry are known (Ewel et al. 1982). The introduction or re-introduction of existing lantana biocontrol agents to Nāulu should be investigated. Outlying firetree or faya in Area IV should be removed to prevent the establishment of this noxious species within the Naulu Special Ecological Area. It would also be desirable to create a buffer zone cleared of faya upslope of the two primay Nāulu kipuka. Control of manageable alien species in important native habitat is recognized as a useful strategy to limit the effects of biological invaders (Vitousek 1988).

2) All kipuka in the Nāulu area that contain lama forest and rare plants should be protected from wildfire. It is essential that the Park continue the current policy of fire suppression near the forests of two primary Nāulu kipuka to prevent the increase of alien grasses and the resulting loss of rare tree species. Park staff should determine whether new fuel breaks are necessary to accomplish protection of Nāulu from fire. The upper section of the easternmost large Nāulu kipuka (Area I) should be examined to evaluate the need for a fuel break below the Chain of Craters Road. Fire and alien grasses are the most serious threats to the restoration and maintenance of dry forests worldwide (Janzen 1988).

3) An outplanting plan to augment the current rare plant populations of Nāulu should be developed, and consideration should be given to establishing satellite populations in nearby kipuka with suitable habitat. Seeds should be collected from several extant rare species not currently reproducing at Nāulu, to permit the propagation of plants for later outplanting the same kipuka; examples of species that might benefit from outplanting are 'ahakea, hame, maua, and 'ohe. It is unlikely that individuals of these four species occur in remaining kipuka or extant forests to the west, where conditions are drier. It would be desirable to survey the forest on the edge of the Mauna Ulu flows north of the study area, as well as kipuka forests on and above Hōlei Pali to the east. The purpose of such a survey would be to establish more thoroughly the distribution of rare tree species in the Park; any rare plants located would also be possible

seed sources for future restoration. Preliminary surveys of two forested kipuka east of Pu'uloa indicated that such forests are relatively low in native plant diversity, but support a few rare trees (D. Palumbo and T. Belfield, pers. comm. 1995).

The remnant Nāulu forest kipuka surveyed during this project may well be the only highly diverse dry forest remaining in the Park. While 'ahakea trees, at least, are known from wetter, higher-elevation sites to the east, these East Rift forests are quite different from the Nāulu dry forest and have recently been subjected to destruction from the ongoing Pu'u 'O'o eruption. Likewise, the one kipuka forest previously known to support a number of 'ohe trees, just upslope of Kamoamoa, has been partially destroyed by lava and fires. Both 'ahakea and 'ohe become greater rarities in Hawaii Volcanoes with each passing year. Hame has never been seen in the Park outside Nāulu Forest, and it is difficult to predict where suitable habitat would be found outside the study area. Maua is a more widely distributed species, and populations are known from both montane rain forest and mesic kipuka forest. However, lowland occurrences of the species are extremely rare in the Park. The justification for augmenting Nāulu with outplanted maua, as well as hame and 'ohe, is that all three species are in danger of being lost from Park dry forests.

Naturally, any rare plant outplanting program to restore the natural biodiversity of Nāulu Forest should only be undertaken after a Park rare plant management plan and a Nāulu outplanting plan have been developed, and all propagation and outplanting should be done in accordance with accepted practices for rare plants in Hawai'i (Woolliams and Llop 1993). If 'ahakea progresses beyond candidacy and is listed as endangered, all required permits should be obtained from the U. S. Fish and Wildlife Service before any seed collection or manipulation is initiated. In continental tropical dry forests, dry forest species are considered to be particularly robust, and even small population fragments may be managed to produce viable populations and restored habitats (Janzen 1988). Restoration of damaged ecosystems may be viewed as a means to increase diversity to pre-disturbance levels and a way to provide refuges for rare and endangered species (Cairns 1988).

4) Rare plant species that have been lost from the Park or the area in the last 20-50 years should be restored to Nāulu Forest; examples of such species are kulu'i, kauila, and kūpala. As with rare plant augmentation, an outplanting plan should be developed that utilizes propagules from the nearest extant population and follows accepted rare plant propagation and outplanting procedures. Kulu'i has not been seen in the Park for more than 20 years, indicating that the species has been lost. One former kulu'i site was searched during this project; the second site on Hilina Pali should also be surveyed to confirm the plant's suspected disappearance. Former kauila habitat below Kipuka Nēnē was briefly searched during another project in 1995. As no kauila trees were found and the area burned in the last decade, this species, too, may have been lost from the Park, except as plantings and widely scattered natural individuals. Former kauila habitat in forests and shrublands near Kipuka Nēnē and Hilina Pali should be more thoroughly

surveyed to determine the current status of kauila in the Park. If restoration of these two species is deemed worthy, seed sources for kauila exist in planted trees within the Park, but propagation material for kulu'i (seeds and cuttings) would have to be collected from outside the Park in Ka'ū. Kūpala vines have not been observed in the Park for more than 50 years; outside sources of seeds would have to be investigated.

5) Extant rare plants of Nāulu and selected common plants that are keystone species of the dry forest (lama, naio, alahe'e) should be monitored to obtain a greater understanding of the dry forest system. Because dry forest is such a rare vegetation type in the Park (as well as in the Hawaiian Islands), it would be desirable to establish permanent vegetation plots to monitor dry forest composition and structure. Such research would help Park managers evaluate whether adequate reproduction and establishment necessary to maintain the forest are taking place. Investigation of the role of rats (Rattus spp.) as limiting factors in rare plant species reproduction in the dry forest would also be valuable, particulary if rare plant restoration or augmentation were undertaken.

LITERATURE CITED

Allen, M.S. 1979. Kalapana extension in the 1800's: a research of the historical records. Unpublished manuscript, Library, Hawaii Volcanoes National Park. 85 pp.

Anderson, S.J., L.W. Pratt, and J.T. Tunison. 1988. Botanical survey of the East Rift Special Ecological Area, Hawaii Volcanoes National Park. Unpublished data, National Park Service and National Biological Service.

Baker, J.K. and D.W. Reeser. 1972. Goat management problems in Hawaii Volcanoes National Park, a history, analysis, and management plan. Natural Resources Report No. 2. U. S. Department of the Interior, National Park Service, Office of the Chief Scientist, Washington, D. C. 22 pp.

Biondini, M.E., P.W. Mielke, Jr., and E.F. Redente. 1988. Permutation techniques based on Euclidean analysis spaces: a new and powerful statistical method for ecological research. Coenoses 3(3): 155-174.

Cairns, J. Jr. 1988. Increasing diversity by restoring damaged ecosystems. pp. 333-343 In E. O. Wilson (Ed.) Biodiversity. National Academy Press, Washington, D.C.

Camrath, R. and T. Tunison. In prep. The distribution of Myrica faya within Hawaii Volcanoes National Park. Cooperative National Park Resources Studies Unit Technical Report, University of Hawaii at Manoa, Department of Botany, Honolulu.

Char, W.P. and C.H. Lamoureux. 1985. Puna geothermal area biotic assessment, Puna District, County of Hawaii. Final Report. A report prepared for the Hawaii State Department of Planning and Economic Development. Department of Botany, University of Hawaii at Manoa. 126 pp. & appendices.

Clausen, C.P. (Ed.) 1978. Introduced parasites and predators of arthropod pests and weeds: a world review. Agricultural Handbook No. 480. U. S. Department of Agriculture, Agricultural Research Service. Washington, D.C. 548 pp.

Cuddihy, L.W. and C.P. Stone. 1990. Alteration of native Hawaiian vegetation; effects of humans, their activities, and introductions. University of Hawaii Cooperative National Park Resources Studies Unit. University of Hawaii Press, Honolulu. 138 pp.

Doty, M.S. and D. Mueller-Dombois. 1966. Atlas for bioecology studies in Hawaii Volcanoes National Park. University of Hawaii Botanical Science Paper No. 2. Botany Department, University of Hawaii, Honolulu. 507 pp.

Ellis, W. 1963 [Reprint of 1827 edition]. Journal of William Ellis. Narrative of a tour of Hawai'i or Owhyhee; with remarks on the history, traditions, manners, customs, and language of the inhabitants of the Sandwich Islands. Advertiser Publishing Co., Ltd., Honolulu. 342 pp.

Ewel, J.J., D.S. Ojima, D.A. Karl, and W.F. DeBusk. 1982. Schinus in successional ecosystems of Everglades National Park. South Florida Research Center Report T-676. 141 pp.

Fagerlund, G.O. 1947. The exotic plants of Hawaii National Park. National Park Service. Natural History Bulletin No. 10, Hawaii National Park. 62 pp.

Fagerlund, G.O. and A.L. Mitchell. 1942-47. Botanical field forms and collection notes, Hawaii National Park. Unpublished, Herbarium, Hawaii Volcanoes National Park.

Fagerlund, G.O. and A.L. Mitchell. 1944. A checklist of the plants, Hawaii National Park, Kilauea-Mauna Loa section, with a discussion of the vegetation. National Park Service. Natural History Bulletin No. 9. Hawaii National Park. 65 pp.

Fosberg, F.R. 1966. Vascular plants. Pp. 153-238 In M.S. Doty and D. Mueller-Dombois. Atlas for bioecology studies in Hawaii Volcanoes National Park. University of Hawaii Botanical Science Paper No. 2. Botany Department, University of Hawaii, Honolulu.

Fosberg F.R. and D. Herbst. 1975. Rare and endangered species of Hawaiian vascular plants. Allertonia 1(1): 1-72.

Giambelluca, T.W., M.A. Nullet, and T.A. Schroeder. 1986. Rainfall atlas of Hawai'i. Report R76. Water Resources Research Center, University of Hawaii with the Cooperation of Department of Meteorology. State of Hawaii Department of Land and Natural Resources, Division of Water and Land Development, Honolulu. 267 pp.

Hawaii Department of Land and Natural Resources. 1970. An inventory of basic water resources data, island of Hawaii. Report R34. State of Hawaii, Division of Water and Land Development. Honolulu. 188 pp.

Holcomb, R.T. 1987. Eruptive history and long-term behavior of Kilauea Volcano. Chapter 12, pp. 261-350 In R.W. Decker, T.L. Wright, and P.H. Stauffer (Eds.). Volcanism in Hawaii, U. S. Geological Survey Professional Paper 1350, Vol. 1. U.S. Government Printing Office, Washington.

Hosaka, E.Y. and A. Thistle. 1954. Noxious plants of the Hawaiian ranges. Hawaii Agricultural Experiment Station Bulletin 62. University of Hawaii College of Agriculture, Extension Service. Honolulu. 39 pp.

Hughes, F., P.M. Vitousek, and T. Tunison. 1991. Alien grass invasion and fire in the seasonal submontane zone of Hawai'i. Ecology 72(2): 743-746.

Jacobi, J.D. 1982. Vegetation map overlay, Makaopuhi Crater, Hawaii. Hawaii Forest Bird Survey, U. S. Fish and Wildlife Service.

Janzen, D.H. 1988. Tropical dry forests, the most endangered major tropical ecosystem. pp. 130-137 In E.O. Wilson (Ed.). Biodiversity. National Academy Press, Washington, D.C.

Kirch, P.V. 1982. The impact of prehistoric Hawaiians on the Hawaiian ecosystem. Pacific Science 36(1): 1-14.

Ladefoged, T., G.F. Somers, and M.M. Lane-Hamasaki. 1987. A settlement pattern analysis of a portion of Hawaii Volcanoes National Park. Western Archeological and Conservation Center Publication in Anthropology No. 44. National Park Service. 161 pp.

Lamoureux, C.H., D. Mueller-Dombois, and K.W. Bridges. 1981. Temporal variation of organism groups studied - Trees. Pp. 391-407 In D. Mueller-Dombois, K.W. Bridges, and H.L. Carson (Eds.). Island ecosystems, biological organization in selected Hawaiian communities. US/IBP Synthesis Series 15. Hutchinson Ross Publishing Company, Stroudsburg, Pennsylvania.

MacDonald, G.A., A.T. Abbott, and F.L. Peterson. 1983. Volcanoes in the sea; the geology of Hawaii. University of Hawaii Press, Honolulu. 517 pp.

Morris, D.K. 1967. The history of native plant propagation and re-introduction in Hawaii Volcanoes National Park. Unpublished, Library, Hawaii Volcanoes National Park. 37 pp. & figures.

Mueller-Dombois, D. 1980. Spatial variation and vegetation dynamics in the coastal lowland ecosystem, Hawaii Volcanoes National Park. Pp. 235-247 In C.W. Smith (Ed.). Proceedings Third Conference in Natural Sciences, Hawaii Volcanoes National Park. Cooperative National Park Resources Studies Unit, University of Hawaii at Manoa, Department of Botany, Honolulu.

Mueller-Dombois, D. and H. Ellenberg. 1974. Aims and methods of vegetation ecology. John Wiley & Sons, New York. 547 pp.

Nagata, K.M. 1985. Early plant introductions in Hawai'i. The Hawaiian Journal of History 19: 35-61.

National Park Service. 1985. Draft land protection plan, Hawaii Volcanoes National Park. Unpublished plan, Library, Hawaii Volcanoes National Park. 40 pp. & appendices.

National Park Service. 1996. Resources Management Plan, Hawaii Volcanoes National Park. Revised February 15, 1996. Unpublished plan, Resources Management Division, Hawaii Volcanoes National Park. 177 pp. & appendices.

Pratt, L.W. and L.L. Abbott. In prep. Rare plants within managed units of 'Ōla'a Forest, Hawaii Volcanoes National Park. Cooperative National Park Resources Studies Unit Technical Report, University of Hawaii at Manoa, Department of Botany, Honolulu.

Pratt, L.W., L.L. Abbott, and D.K. Palumbo. In prep. a. Rare plants of Kipuka Puaulu, Mauna Loa, Hawaii Volcanoes National Park. Cooperative National Park Resources Studies Unit Technical Report, University of Hawaii at Manoa, Department of Botany, Honolulu.

Pratt, L.W., L.L. Abbott, and D.K. Palumbo. In prep. b. Vegetation above a feral pig barrier fence in rain forests of Kilauea East Rift, Hawaii Volcanoes National Park. Cooperative National Park Resources Studies Unit Technical Report, University of Hawaii at Manoa, Department of Botany, Honolulu.

Rock, J.F. 1974 [Reprint of 1913 edition]. The indigenous trees of the Hawaiian Islands. Pacific Tropical Botanical Garden, Lawai, Hawaii, and Charles E. Tuttle Co., Rutland, Vermont and Tokyo, Japan. 548 pp.

St. John, H. 1980. Variations of Reynoldsia (Araliaceae) in the Hawaiian Islands. Hawaiian Plant Studies 100. Phytologia 46: 154.

Sato, H.H., W. Ikeda, R. Paeth, R. Smythe, and M. Takehiro, Jr. 1973. Soil survey of the island of Hawaii, State of Hawaii. U. S. Department of Agriculture, Soil Conservation Service, in cooperation with the University of Hawaii Agricultural Experiment Station. 115 pp & maps.

Sherff, E.E. 1947. A preliminary study of the Hawaiian species of the genus Rauvolfia (Plum.) L., family Apocynaceae. Field Museum Natural History. Botanical Series 23: 321-331.

Sherff, E.E. 1952. Further studies of Hawaiian Araliaceae; additions to Cheirodendron helleri Sherff and a preliminary treatment of the endemic species of Reynoldsia A. Gray. Sherff's Botanical Leaflet 6: 6-19.

Slauson, W.L., B.S. Cade, and J.D. Richards. 1994. User manual for BLOSSOM statistical software. Midcontinent Ecological Science Center, National Biological Survey. Fort Collins, Colorado. [Revision of January 1991 version.]

Smith, C.W. 1985. Impacts of alien plants on Hawai'i's natural biota. Pp. 180-250 In C.P. Stone and J.M. Scott (Eds.) Hawai'i's terrestrial ecosystems: preservation and management. Cooperative National Park Resources Studies Unit. University of Hawaii at Manoa, Honolulu.

Smith, C.W. and J.T. Tunison. 1992. Fire and alien plants in Hawai'i: research and management implications for native ecosystems. Pp. 394-408 In C.P. Stone, C.W. Smith, and J.T. Tunison (Eds.) Alien plant invasions in native ecosystems of Hawai'i: management and research. University of Hawaii Cooperative National Park Resources Studies Unit. University of Hawaii Press, Honolulu.

Stemmermann, L. 1980. Observations on the genus Santalum (Santalaceae) in Hawai'i. Pacific Science 34(1): 41-54.

Stemmermann, L. and T. Ihsle. 1993. Replacement of Metrosideros polymorpha, 'ōhi'a, in Hawaiian dry forest succession. Biotropica 25(1): 36-45.

Stone, B.C. 1959. Natural and cultural history report on the Kalapana Extension of the Hawaii National Park. Part Two. Plants of the Kalapana Extension, Hawaii National Park. Natural History Report, Bernice P. Bishop Museum, Honolulu. 66 pp.

Stone, C.P. and L.W. Cuddihy. 1990. Special ecological areas (SEAs): ecology, inventory, monitoring, and response to management. Hawaii Volcanoes National Park. Unpublished proposal, Research Division, Hawaii Volcanoes National Park. 16 pp.

The Nature Conservancy of Hawaii. 1987. Biological overview of Hawaii's Natural Area Reserves System, Appendices. Hawaii State Department of Land and Natural Resources and Hawaii Heritage Program, Honolulu. 47 pp.

The Nature Conservancy of Hawaii. 1990. The Hawaiian Natural Community Classification, Summary Listing. Hawaii Heritage Program, Honolulu. 27 pp.

Tomich, P.Q. 1986. Mammals in Hawai'i: a synopsis and notational bibliography, Second edition. Bernice P. Bishop Museum Special Publication 76. Bishop Museum Press, Honolulu. 375 pp.

Tunison, J.T., C.P. Stone, and L.W. Cuddihy. 1986. SEAs provide ecosystem focus for management and research. Park Science 6(3): 10-13.

Tunison, J.T., J.A.K. Leialoha, R.L. Loh, L.W. Pratt, and P.K. Higashino. 1994. Fire effects in the coastal lowlands of Hawai'i Volcanoes National Park. Cooperative National Park Resources Studies Unit Technical Report 88. University of Hawaii at Manoa, Department of Botany, Honolulu. 43 pp.

Tunison, J.T., J.A.K. Leialoha, and R.L. Loh. In prep. A fire history atlas of Hawaii Volcanoes National Park, 1916-1995. Cooperative National Park Resources Studies Unit Technical Report. University of Hawaii at Manoa, Department of Botany, Honolulu.

U.S. Fish and Wildlife Service, Department of the Interior. 1980. Endangered and threatened wildlife and plants: review of plant taxa for listing as endangered or threatened species. Federal Register 45(242): 82480-82569.

U.S. Fish and Wildlife Service, Department of the Interior. 1994a. Plants, Hawaiian Islands; Species being considered for proposed status in 1995 and candidate. extinct, or recommended species under the U. S. Endangered Species Act. Updated: November, 1994.

U.S. Fish and Wildlife Service, Department of the Interior. 1994b. Endangered and threatened wildlife and plants; determination of endangered or threatened status for 21 plants from the island of Hawaii, State of Hawaii. Federal Register 59(43): 10305-10325.

U.S. Fish and Wildlife Service, Department of the Interior. 1995. Endangered and threatened wildlife and plants; proposed status for thirteen plants from the island of Hawaii, State of Hawaii. Federal Register 60(185): 49377-49392.

Vitousek, P.M. 1988. Diversity and biological invasions of oceanic islands. Pp. 181-189 In E.O. Wilson (Ed.). Biodiversity. National Academy Press, Washington, D.C.

Wagner, W.H. Jr. 1950 Ferns naturalized in Hawaii. Occasional Papers of Bernice P. Bishop Museum 20(8): 95-121.

Wagner, W.L., D.R. Herbst, and S.H. Sohmer. 1990. Manual of the Flowering Plants of Hawai'i. Bishop Museum Special Publication 83. University of Hawaii Press and Bishop Museum Press, Honolulu. 1854 pp.

Warshauer, F.R. 1974. Biological survey of Kealakomo and vicinity affected by 1969-1973 lava generated wildfires, Hawaii Volcanoes National Park. Unpublished report, Library, Hawaii Volcanoes National Park. 42 pp.

Warshauer, F.R. and J.D. Jacobi. 1973. A biological survey of the lower Kamoamoa and Pulama sections of Hawaii Volcanoes National Park. U.S. International Biological Program, Island Ecosystems IRP. Unpublished report, Library, Hawaii Volcanoes National Park. 18 pp.

Whitney, L.D., E.Y. Hosaka, and J.C. Ripperton. 1964 [Reprint of 1939 edition]. Grasses of the Hawaiian ranges. Hawaii Agricultural Experiment Station Bulletin 82. University of Hawaii. Honolulu, T.H. 148 pp.

Williams, J. 1990. The coastal woodland of Hawaii Volcanoes National Park: vegetation recovery in a stressed ecosystem. Cooperative National Park Resources Studies Unit Technical Report 72. University of Hawaii at Manoa, Department of Botany, Honolulu. 78 pp.

Woolliams, K.R. and J.L. Llop. 1993. Guidelines for "outplanting". Waimea Arboretum, Waimea, O'ahu. 4 pp.

Yang, P., D. Foote, V.P. Jones, and J.T. Tunison. In prep. A preliminary investigation of the effect of two-spotted leafhopper, Sophonia rufofascia (Kuoh & Kuoh), on firetree, Myrica faya Aiton, in Hawaii Volcanoes National Park. Cooperative National Park Resources Studies Unit Technical Report. University of Hawaii at Manoa, Department of Botany, Honolulu.

Zimmer, N.G. 1982-83. Rare plant packets and maps. Unpublished reports in files, Resources Management Division, Hawaii Volcanoes National Park.

APPENDIX I
CHECKLIST OF VASCULAR PLANTS IN NĀULU SEA

	Status	Area I	Area II	Area IV
FERNS AND FERN ALLIES				
ASPLENIACEAE - Spleenwort Family				
Asplenium adiantum-nigrum L. 'Iwa'iwa	I			R
BLECHNACEAE - Chain Fern Family				
Blechnum occidentale L. Occidental blechnum	A			R
Sadleria cyatheoides Kaulf. 'Ama'u	E			R
DRYOPTERIDACEAE (NEPHROLEPIDOIDEAE) - Woodfern Family (Swordfern Subfamily)				
Nephrolepis multiflora (Roxb.) F. M. Jarrett ex C. V. Morton (Syn: Nephrolepis hirsutula) Scaly swordfern	A	A	A	U
POLYPODIACEAE - Polypody Family				
Lepisorus thunbergianus (Kaulf.) Ching (Syn: Pleopeltis thunbergiana) 'Ekaha 'ākōlea	I	R	U	
Phlebodium aureum (L.) J. Sm. Golden polypody	A	R	R	
Phymatosorus grossus (Langsd. & Fisch.) Brownlie Laua'e	A	C	O	U
Polypodium pellucidum Kaulf. 'Ae	E		R	
PSILOTACEAE - Whisk fern Family				
Psilotum nudum (L). P. Beauv. Moa, whisk fern	I	O	U	U
PTERIDACEAE - Maidenhair Fern Family				
Doryopteris decora Brack. 'Iwa'iwa	E	O	U	O

APPENDIX I (CONTINUED)
CHECKLIST OF VASCULAR PLANTS IN NĀULU SEA

	Status	Area I	Area II	Area IV
PTERIDACEAE - Maidenhair Fern Family (Continued)				
Pellaea ternifolia (Cav.) Link Kalamoho	I		R	U
Pteris vittata L. Kīlau o pueo	A			R
FLOWERING PLANTS - DICOTS				
ANACARDIACEAE - Mango Family				
Schinus terebinthifolius Raddi Christmas berry	A	U	U	U
APOCYNACEAE - Dogbane Family				
Rauvolfia sandwicensis A. DC. (Syn: Rauvolfia remotiflora) Hao	E	R		
ARALIACEAE - Ginseng Family				
Reynoldsia sandwicensis A. Gray 'Ohe, 'ohe makai	E		R	
ASCLEPIADACEAE - Milkweed Family				
Asclepias physocarpa (E.Mey.) Schlechter (Syn: Gomphocarpus physocarpus) Balloon plant	A	R	R	U
ASTERACEAE (COMPOSITAE) - Sunflower Family				
Ageratina riparia (Regel) R. King & H. Robinson (Syn: Eupatorium riparium) Spreading mist flower, Hamakua pāmakani	A			U
Bidens pilosa L. Spanish needle	A	U		
Conyza bonariensis (L.) Cronq. (Syn: Erigeron bonariensis) Fleabane	A		R	R

APPENDIX I (CONTINUED)
CHECKLIST OF VASCULAR PLANTS IN NĀULU SEA

	Status	Area I	Area II	Area IV
ASTERACEAE - Sunflower Family (Continued)				
Emilia fosbergii Nicolson Pua lele	A			U
Emilia sonchifolia (L.) DC Flora's paintbrush	A		R	R
Gnaphalium purpureum L. Purple cudweed	A			R
Pluchea symphytifolia (Mill.) Gillis (Syn: Pluchea odorata) Sourbush	A	C	O	O
Vernonia cinerea (L.) Less. var. parviflora (Reinw.) DC Little ironweed	A			U
CONVOLVULACEAE - Morning glory Family				
Ipomoea indica (J. Burm.) Merr. (Syn: Ipomoea congesta) Koali'awa, koali'awahia	I	O		
CRASSULACEAE - Orpine Family				
Kalanchoe pinnata (Lam.) Pers. (Syn: Bryophyllum pinnatum) Air plant	A		R,lc	
EBENACEAE - Ebony Family				
Diospyros sandwicensis (A. DC.) Fosb. (Syn: Diospyros ferrea) Lama	E	C	C	O
EPACRIDACEAE - Epacris Family				
Styphelia tameiameiae (Cham. & Schlechtend.) F. v. Muell. Pūkiawe	I	O		C
EUPHORBIACEAE - Spurge Family				
Aleurites moluccana (L.) Willd. Kukui	P	C,lc	O	
Antidesma pulvinatum Hillebr. Hame, mehame	E	R		

APPENDIX I (CONTINUED)
CHECKLIST OF VASCULAR PLANTS IN NĀULU SEA

	Status	Area I	Area II	Area IV
EUPHORBIACEAE - Spurge Family (Continued)				
Phyllanthus debilis Klein ex Willd. Niruri	A	U		
FABACEAE (LEGUMINOSAE) - Pea Family				
Caesalpinia bonduc (L.) Roxb. Kākalaioa	I	U		
Chamaecrista nictitans (L.) Moench subsp. patellaria (DC ex Collad.) H. Irwin & Barneby var. glabrata (Vogel) H. Irwin & Barneby (Syn: Cassia leschenaultiana) Partridge pea	A	O	O	O
Crotalaria pallida Aiton (Syn: Crotalaria mucronata) Smooth rattle pod	A	U		
Desmodium sandwicense E. Mey. (Syn: Desmodium uncinatum) Spanish clover	A	O		U
Desmodium triflorum (L.) DC Three-flowered beggarweed	A	O	U	O
Desmodium sp. Beggarweed	A			U,lc
Indigofera suffruticosa Mill. Indigo	A	U	U	U
Senna gaudichaudii (Hook. & Arnott) H. Irwin & Barneby (Syn: Cassia gaudichaudii) Kolomona	I	R		
Sophora chrysophylla (Salisb.) Seem. Māmane	E	U		R
FLACOURTIACEAE - Flacourtia Family				
Xylosma hawaiiense Seem. Maua	E	R	R	R
LAMIACEAE (LABIATAE) - Mint Family				
Hyptis pectinata (L.) Poit. Comb hyptis	A	U		

APPENDIX I (CONTINUED)
CHECKLIST OF VASCULAR PLANTS IN NĀULU SEA

	Status	Area I	Area II	Area IV
LAMIACEAE - Mint Family (Continued)				
Plectranthus parviflorus Willd. (Syn: Plectranthus australis) 'Ala'alawainui pua kī	I	O	O	R
Salvia occidentalis Sw. West Indian sage	A	U		
LAURACEAE - Laurel Family				
Cassytha filiformis L. Kauna'oa pehu	I	U	U	
MALVACEAE - Mallow Family				
Sida fallax Walp. 'Ilima	I	R	R	R
MENISPERMACEAE - Moonseed Family				
Cocculus trilobus (Thunb.) DC Huehue	E	U	O	R
MYOPORACEAE - Myoporum Family				
Myoporum sandwicense A. Gray Naio	I	U	O	O
MYRICACEAE - Myrica Family				
Myrica faya Aiton Firetree, faya	A			O
MYRTACEAE - Myrtle Family				
Metrosideros polymorpha Gaud. var. incana (H. Lev.) St. John (Syn: Metrosideros collina) 'Ōhi'a lehua	E	C	C	A
Psidium cattleianum Sabine Strawberry guava, waiawi	A	O	U	
Psidium guajava L. Common guava	A	O	U	
OLEACEAE - Olive Family				
Olea europaea L. subsp. africanus (Mill.) P. Green (Syn: Linociera ligustrina in Hawai'i) Olive	A			U

APPENDIX I (CONTINUED)
CHECKLIST OF VASCULAR PLANTS IN NĀULU SEA

	Status	Area I	Area II	Area IV
PASSIFLORACEAE - Passionflower Family				
Passiflora edulis Sims Liliko'i	A		R	
PIPERACEAE - Pepper Family				
Peperomia leptostachya Hook. & Arnott 'Ala'ala wai nui	I	O	O	
POLYGONACEAE - Buckwheat Family				
Polygonum capitatum F. Ham. Knotweed	A	R		U,lc
ROSACEAE - Rose Family				
Osteomeles anthyllidifolia (Sm.) Lindl. 'Ūlei	I	R		O
RUBIACEAE - Coffee Family				
Bobea timonioides (J. D. Hook.) Hillebr. 'Ahakea	E	R	R	
Canthium odoratum (G. Forster) Seem. (Now called Psydrax odorata) Alahe'e	I	C	C	U
SANTALACEAE - Sandalwood Family				
Santalum paniculatum Hook. & Arnott var. paniculatum 'Iliahi, sandalwood	E	R	U	
SAPINDACEAE - Soapberry Family				
Dodonaea viscosa Jacq. 'A'ali'i	I	O	C	C
SOLANACEAE - Nightshade Family				
Capsicum frutescens L. Bird pepper	A	R		

APPENDIX I (CONTINUED)
CHECKLIST OF VASCULAR PLANTS IN NĀULU SEA

	Status	Area I	Area II	Area IV
STERCULIACEAE - Cacao Family				
Waltheria indica L. (Syn: Waltheria americana) 'Uhaloa, hi'aloa	I	O	O	U
VERBENACEAE - Verbena Family				
Lantana camara L. Lantana	A	A	A	O
Stachytarpheta dichotoma (Ruiz & Pav.) Vahl (Syn: Stachytarpheta cayennensis) Vervain, oi	A	O	U	U
Verbena litoralis Kunth Vervain, ōwī, oi	A		U	
FLOWERING PLANTS-MONOCOTS				
AGAVACEAE - Agave Family				
Cordyline fruticosa (L.) A. Chev. (Syn: Cordyline terminalis) Kī, ti	P			R
Pleomele hawaiiensis Degener & I. Degener Hala pepe	E	R	R	
CYPERACEAE - Sedge Family				
Bulbostylis capillaris (L.) C.B. Clarke No common name	A	O	O	O
Carex wahuensis C. A. Mey. No common name	E			R
Mariscus hillebrandii (Boeck.) T. Koyama var. hillebrandii (Syn: Cyperus hillebrandii) No common name	E			R
ORCHIDACEAE - Orchid Family				
Arundina graminifolia (D. Don) Hochr. (Syn: Arundina bambusaefolia) Bamboo orchid	A	O	U	O

APPENDIX I (CONTINUED)
CHECKLIST OF VASCULAR PLANTS IN NĀULU SEA

	Status	Area I	Area II	Area IV
ORCHIDACEAE - Orchid Family (Continued)				
Spathoglottis plicata Blume Malayan ground orchid	A			O
POACEAE (GRAMINEAE) - Grass Family				
Andropogon virginicus L. Broomsedge	A	C	A	A
Chrysopogon aciculatus (Retz.) Trin. Golden beardgrass	I	U	O	U
Digitaria violascens Link Violet crabgrass	A	U		
Digitaria sp. Unknown crabgrass	A		R	
Melinis minutiflora P. Beauv. Molasses grass	A	O	O	O
Rhynchelytrum repens (Willd.) Hubb. (Syn: Tricholaena rosea) Natal redtop	A	A	A	C
Schizachyrium condensatum (Kunth) Nees (Syn: Andropogon glomeratus) Bush beardgrass	A	C	C	C
Setaria gracilis Kunth (Syn: Setaria geniculata) Yellow foxtail	A		O	
Sporobolus africanus (Poir.) Robyns & Tournay Smutgrass, African dropseed	A	U	U	

SYMBOLS AND ABBREVIATIONS

Status:

E = Endemic, native and unique to the Hawaiian Islands
I = Indigenous, native to the Hawaiian Islands and other lands
P = Polynesian Introduction
A = Alien, non-indigenous, exotic, introduced after 1778

APPENDIX I (CONTINUED)
CHECKLIST OF VASCULAR PLANTS IN NĀULU SEA

SYMBOLS AND ABBREVIATIONS (Continued)

Abundance Rating:

A = Abundant
C = Common, numerous and widespread
O = Occasional, scattered in many localities
U = Uncommon, infrequent, few scattered plants
R = Rare, one or very few plants seen
lc = Localized

Areas:

Area I First large kipuka west of Chain of Craters Road hairpin curve, primary Nāulu Forest kipuka

Area II Second large kipuka west of Chain of Craters Road hairpin curve, ca. 0.75 km west of Area I

Area IV Large kipuka between Hōlei and Poliokeawe Pali, ca. 1.5 km west of Area II

NOMENCLATURE

Nomenclature of ferns and fern allies:

Wagner, W. H. Jr. and F. S. Wagner 1995. Revised tentative checklist of Hawaiian pteridophytes, February 22, 1995, Unpublished manuscript.

Scientific and common names of flowering plants:

Wagner, W. L., D. L. Herbst, and S. H. Sohmer. 1990. Manual of the flowering plants of Hawai'i. Bernice P. Bishop Museum Special Publication 83, University of Hawaii and Bishop Museum Press, Honolulu.

Common names of ferns and some flowering plants:

Porter, J. R. 1972. Hawaiian names for vascular plants. Hawaii Agricultural Experiment Station, University of Hawaii Departmental Paper 1, Honolulu. [Ferns]

St. John, H. 1973. List and summary of the flowering plants in the Hawaiian Islands. Pacific Tropical Botanical Garden Memoir Number 1, Lawai, Kaua'i, Hawai'i. [Flowering plants]

APPENDIX II
VASCULAR PLANT CHECKLIST SUMMARY - NĀULU SEA

	Number of Species (%)							
	Area I		Area II		Area IV		All	
Ferns and Fern Allies	6		8		9		12	
Endemic	1	(17%)	2	(25%)	2	(22%)	3	
Indigenous	2	(33%)	3	(38%)	3	(33%)	4	
Polynesian	0	(0%)	0	(0%)	0	(0%)	0	
Alien	3	(50%)	3	(38%)	4	(44%)	5	
Flowering Plants - Dicots	41		31		32		54	
Endemic	9	(22%)	7	(23%)	5	(16%)	13	
Indigenous	13	(32%)	8	(26%)	8	(25%)	13	
Polynesian	1	(2%)	1	(3%)	0	(0%)	1	
Alien	18	(43%)	15	(48%)	19	(59%)	27	
Flowering Plants - Monocots	10		11		11		16	
Endemic	1	(10%)	1	(9%)	2	(18%)	3	
Indigenous	1	(10%)	1	(9%)	1	(9%)	1	
Polynesian	0	(0%)	0	(0%)	1	(9%)	1	
Alien	8	(80%)	9	(82%)	7	(64%)	11	
Total - Vascular Plants	57		50		52		82	
Endemic	11	(19%)	10	(20%)	9	(17%)	19	
Indigenous	16	(28%)	12	(24%)	12	(23%)	18	
Polynesian	1	(2%)	1	(2%)	1	(2%)	2	
Alien	29	(51%)	27	(54%)	30	(58%)	43	